[INFORMATION AND COMMUNICATIONS TECHNOLOGY AND DISASTER RISK REDUCTION DIVISION]

Managing in-land water disasters in the Aral Sea: sub-regional pathways for adaptation and resilience

An analysis of climate change impact on the Aral Sea transboundary hazard

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About the report

Managing in-land water disasters in the Aral Sea: sub-regional pathways for adaptation and resilience is an analytical research study that brings out comprehensive economic, social and environmental assessment of the Aral Sea catastrophe as well as provides the latest scientific evidence on the climate crisis using a multi-sectoral and multi-disciplinary approach. It also presents a strategic perspective on developing a subregional transboundary cooperation framework to reduce and mitigate disaster risks in inland water basins related to the Aral Sea.

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Photo credits

Cover: a figure of the Aral Sea from unsplash.com.

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Executive summary

The desiccation of the Aral Sea Basin is well studied for its causes and devastating impacts in the surrounding countries, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Over the decades the Aral Sea catastrophe has transformed into a transboundary hazard that has affected the arid and semi-arid regions of Central Asia. It's important to recognise that teleconnections[1] exist between natural resources and natural ecosystem services in a transboundary hazard. While economic and social linkages alter this teleconnection, climate change substantially contributes to the imbalance.

This study 'managing in-land water disasters in the Aral Sea: sub-regional pathways for adaptation and resilience' capitalizes on state-of-the-art climate modelling, data science, geo-spatial tools, digital elevation models and analytics to present the risk in the region. It zooms in on the Aral Sea as a transboundary hazard Fand visualizes the climate risk scenarios in the near (2021-2040) and long-term (2081-2100) perspectives. The study finds that under the Shared Socio-economic Pathways (SSP) 2 (moderate) near-term and SSP 3 (worst-case) long-term, the projected average increase of annual mean temperature is between 1.12 to 4.66°C in Central Asia, including in the Aral Sea. Further, projections show that the average increase of annual consecutive dry days under SSP2 near-term to SSP3 long-term is between 2 to 4 days, while the maximum consecutive dry days increase ranges from 13 to 14 days. With regards to precipitation, the study projects average decrease of maximum 5-day precipitation in June-August under SSP2 near-term to SSP3 long-term to between 1.66 to 4.49 mm in Central Asia. The projected average increase of maximum 5-day precipitation in December to February under SSP2 near-term to SSP3 long-term is between 6.59 to 26.64 mm in Central Asia. As the result, floods are projected to be more severe and prolonged, while droughts are likely to be more frequent and lengthier in the surroundings of the Aral Sea.

The key indicator of climate change in Central Asia is the state of glaciers and snow cover, as well as growing desertification in the region. The changing climate scenarios that characterize the Aral Sea are projected by decrease in summer rainfall, increasing number of dry days and temperature resulting in higher aridity. On contrary, there are likely to be increasing winter rainfall with increasing number of rainy days. The elevation of the Aral Sea also contributes to the changing patterns of the climate scenarios. Further, land use changes and water management practices are likely to result in many clusters of agricultural risk hotspots. It is key to note that warming climate in the Aral Sea does not pose just one risk, but multiple, interacting risks. The complexity of these interactions among multiple drivers of climate and other forms of the risk compounds and cascades in the Aral Sea. Hence, the focus of physical science research for these "compounding" risk is to integrate and understand the multiple interactions among drivers of exposure, vulnerability, and response.

The taxonomy of solutions for climate change adaptation and disaster resilience must recognize the compounding risk scenarios that characterize the Aral Sea. Considering a transboundary hazard – the Aral Sea that represents shared vulnerabilities and risks, adaptation measures must include integration of the climate change scenarios into various medium and long-term plans, programs, etc., both at the national and sub-regional levels. It is in this context that the study introduces a set of adaptation priorities – (i) strengthening multi-hazard risk assessment and early-warning systems; (ii) improving dryland agriculture crop production; (iii) making water resources management more resilient; (iv) nature-based solutions; and (v) making new infrastructure resilient. Derived from its unique compounding and cascading risk profiles, adaptation priorities for managing and mitigating in-land water disasters in the Aral Sea also support simultaneous progress on multiple SDGs (Figure A).

It's crucial for the adaptation priorities of transboundary Aral Sea hazard to be risk with information on the regional specificities. (Figure B). For example, multi-hazard risk assessment and early warning

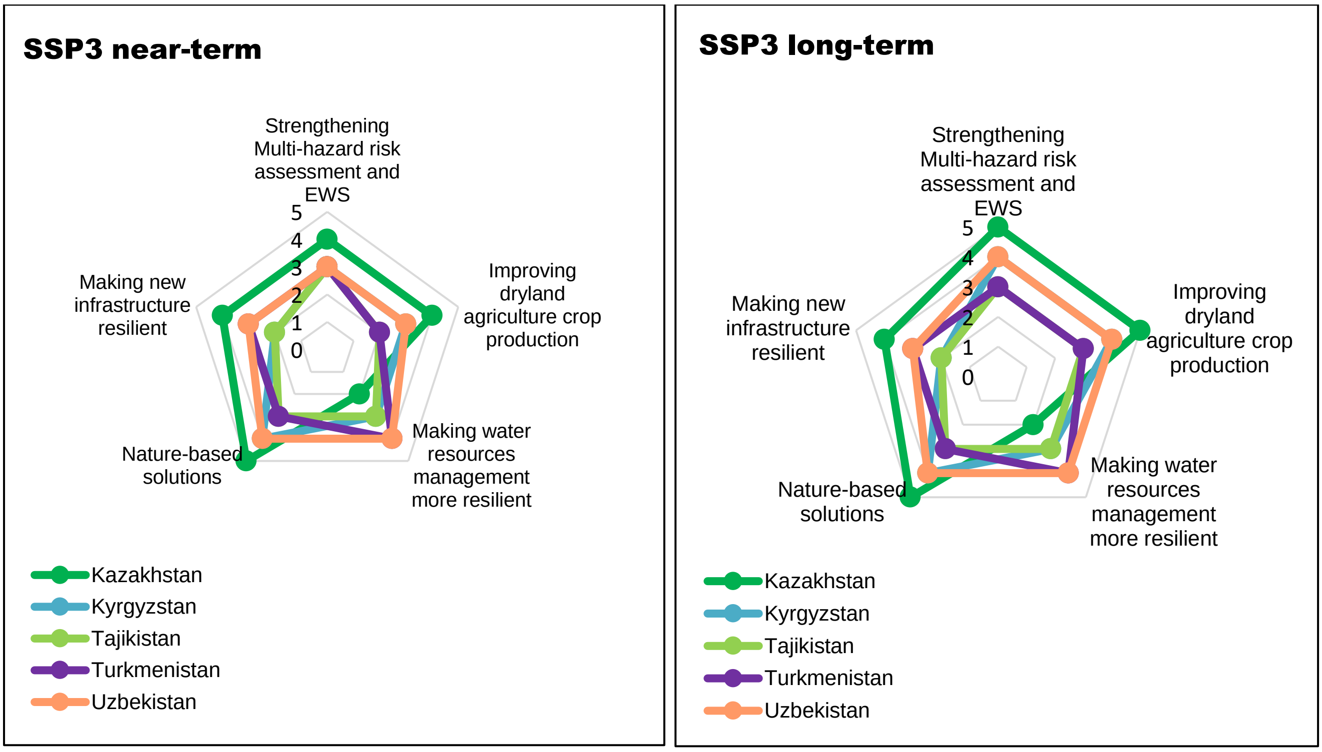
[1] The word 'teleconnections' in this report has been used to imply all those direct and indirect connections between causes and effects separated by geographical distance in their occurrence in specific context of a transboundary hazard – the Aral Sea.

systems are highly useful in mitigating all types of cropland exposure to multi-hazard, particularly drought, and flood. Early warning monitoring is necessary to plan and reduce the impact of multi-hazard on agriculture, which is directly linked to food security, and the impact of multi-hazard on people. Adaptation priorities to Strengthen Multi-hazard risk assessment and Early warning systems and Improving dryland agriculture crop production have the highest scores for all 5 countries in all the different climate change scenarios, consistent with SSPs.

Figure A – Climate adaptation priorities matrix for the Aral Sea vis-à-vis cluster of SDGs

Improving dryland agriculture crop production	Making new infrastructure resilient	Making water resources management more resilient	Nature based solutions: green infrastructure	Multi-hazard risk assessment and early warning systems
2 ZERO HUNGER 13 CLIMATE ACTION 15 LIFE ON LAND	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 11 SUSTAINABLE CITIES AND COMMUNITIES 13 CLIMATE ACTION	1 NO POVERTY 2 ZERO HUNGER 11 SUSTAINABLE CITIES AND COMMUNITIES 13 CLIMATE ACTION 14 LIFE BELOW WATER 15 LIFE ON LAND	13 CLIMATE ACTION 14 LIFE BELOW WATER 15 LIFE ON LAND	1 NO POVERTY 2 ZERO HUNGER 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 3 GOOD HEALTH AND WELL-BEING 11 SUSTAINABLE CITIES AND COMMUNITIES 13 CLIMATE ACTION

Figure B – Climate adaptation priorities matrix for the Aral Sea, under the worst-case climate change scenarios



Understanding transboundary risks of the Aral Sea vis-à-vis adaptation priories need to factor in the National Adaptation Plan, National Disaster Risk Reduction strategies, Voluntary National Review, and Nationally Determined Contributions as well as the sectoral (agriculture, water and energy) of all associated countries.

Moving forward, opportunity lies in establishing a sub-regional partnership platform on managing in-land water disasters in the Aral Sea associated with North and Central Asian Multi-Stakeholder Forum on Implementation of Sustainable Development Goals. The fifth session of this forum held in October 2021 discussed the implementation of SDGs 14 and 15 in a changing climate and recommended subregional cooperation mechanisms for addressing transboundary challenges.

The Committee on Disaster Risk Reduction of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) at its 7th session held on 25-27 August 2021 also recommended a scale-up of regional and subregional cooperation strategies on disaster risk reduction and climate resilience to complement national efforts in implementing the 2030 Agenda for Sustainable Development. It's in this context that ESCAP conducted this analytical study as well as companion study on Aral Sea, Central Asian Countries and Climate Change in the 21st Century. Both studies focus on developing regional cooperation mechanism to reduce and mitigate disaster risks in endorheic (inland) water basins related to Aral Sea. The study served as the basis for expert consultation with experts and key stakeholders of the Aral Sea basin during the regional meeting that ESCAP organized on 14 March 2022. Considering ESCAP's mandate and comparative advantage, the experts recommended organizing a policy dialogue on managing the risk of in-land water disasters in the Aral Sea on the side-lines of sixth North and Central Asian Multi-Stakeholder Forum on Implementation of Sustainable Development Goals to shape a subregional cooperation framework with the suggested action plan.

Introduction

The desiccation of the Aral Sea Basin, otherwise known as 'the Aral Sea Catastrophe', has had devastating impacts on lives and livelihoods of the surrounding countries; Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan. These countries are located in arid and semi-arid region. The causes of the Aral Sea catastrophe have been studied from multiple perspectives in the past.[2,3] Some studies have identified increased population and increased irrigated land, as well as deteriorating water infrastructures, as plausible causes of 'the Aral Sea catastrophe'. This calamity has also been attributed to slow onset disasters such as drought, land degradation, desertification and sand and dust storms in form of salt-dust transport. The location of these countries in arid and semi-arid regions, makes them Susceptible to projected increases in dryland under future climate scenarios. In the long-term, this would contribute further to land degradation and desertification.

The recent IPCC Sixth Assessment Report 6 (August 2021) that uses the most advanced version of climate model - Coupled Model Intercomparison Project Phase 6 (CMIP6) highlights that Central Asia is going to experience an increase in hot extremes, especially due to human activities. ESCAP has downscaled the CMIP 6 and analysed climate risk scenarios in the specific context of in-land water disasters, such as the Aral Sea catastrophe. The climate scenarios were analysed in conjunction with three-dimensional digital elevation model using contour lines created with ASTER Global Digital Elevation Model (GDEM). The analysis includes slow onset disasters such as drought, desertification, and land degradation.

In transboundary hazards like the Aral Sea catastrophe, teleconnections exist between natural resources and natural ecosystem services. Economic and social linkages do alter the nature of teleconnection . Climate change impacts are quite substantial in altering this relationship. Therefore, addressing in-land water disasters in the Aral Sea calls for a sub-regional cooperation framework among the key stakeholders. It is in this context that ESCAP has developed a multi-criteria analysis on climate and aridity impact, with CMIP6 climate projection data and the Digital Elevation Model, that predicts the near-term and long-term risk scenarios. To facilitate adaption to the transboundary climate risk confronted by the Aral Sea, a Decision Support System is presented, highlighting the recommended adaptation priority. These include transformative dry land agriculture, resilient water infrastructure, multi-hazard early warning systems both for slow onset and extreme events, putting in place grey and green infrastructure, and nature-based solutions . The adaptation priorities, derived from the unique climate risk profiles of the Aral Sea, correspond to a cluster of SDGs (13, 14 and 15). A sub-regional cooperation mechanism aligned with the SDGs and the Sendai Framework is also recommended to accelerate adaptation and resilience pathways towards managing risks associated with the Aral Sea.

The shrinking of the Aral Sea

The Aral Sea has been gradually drying up due to the increasing demand of water, growing population, and the emerging threat from climate change.[4]

Figure 1-1 shows the satellite imagery of the declining surface area of the Aral Sea in the past two decades. The Aral Sea environmental catastrophe has tremendously impacted people in multiple sectors such as health, food security

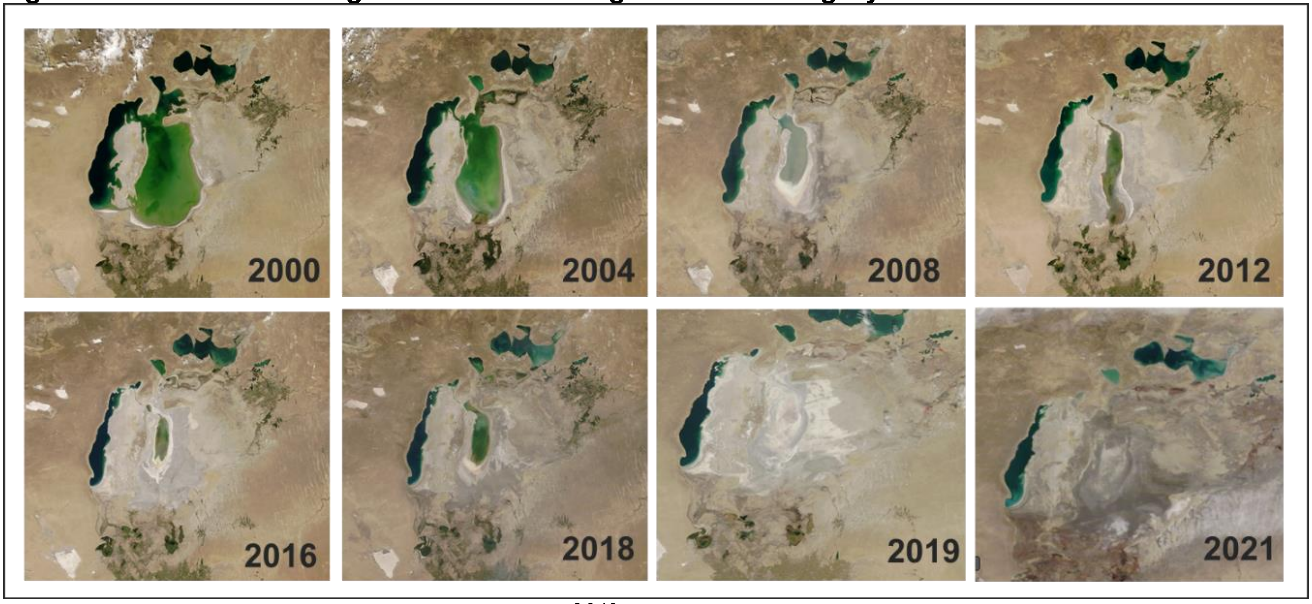
[2] Izhitskiy, A., Zavialov, P., Sapozhnikov, P. and others, (2016). Present state of the Aral Sea: diverging physical and biological characteristics of the residual basins. Sci Rep 6, 23906 (2016). https://doi.org/10.1038/srep23906.

[3] World Meteorological Organization, (2014). The Future of the Aral Sea Lies in Transboundary Co–operation. Bulletin no: Vol 63 (1) – 2014. Available at: https://public.wmo.int/en/resources/bulletin/future-of-aral-sea-lies-transboundary-co%E2%80%93operation.

[4] United Nations, Economic and Social Commission of Asia and the Pacific (ESCAP), (2021). Asia-Pacific Disaster Report 2021. Available at: https://www.unescap.org/kp/2021/asia-pacific-disaster-report-2021.

and critical infrastructure sectors in Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan. In 1960s, the Aral Sea was full of water with river deltas and seaports. The water level was at 53 metres, but dropped to 31 metres by 2002.[5] The agricultural development in the surrounding desert land has intensified the demand for water for irrigation, which resulted in decrease of fresh water flowing into the Aral Sea. This was aggravated by evaporation of the surface water which also played an important role in the dropping sea level. The continual desiccation of the Aral sea has resulted in a decrease of over 90 per cent of the sea volume in the 5 decades between late 1950s and 2009 (Figure 1-2 b).[6] Similarly, by 2013, the surface area of the Aral Sea was less than one sixth of its original area, only 5 decades earlier[7] (Figure 1-2 a). This trend continues today, with visibly greater desiccation of the Aral Sea between 2000 and 2021 (Figure 1-1).

Figure 1-1 – The shrinking of Aral Sea through satellite imagery

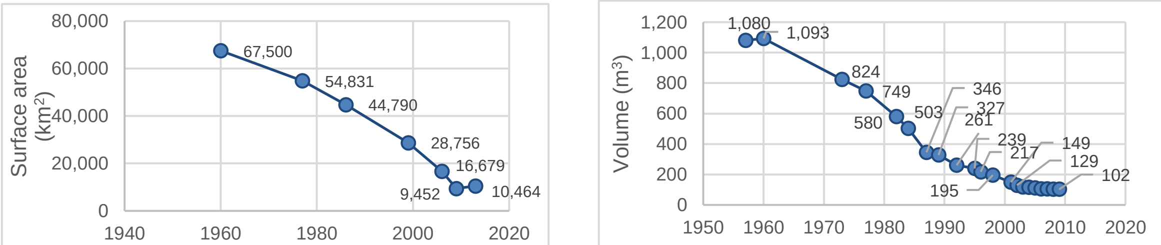


Source : (MODIS) on NASA's Terra satellite[8,9,10]
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1-2 – Changes in surface area and volume of Aral Sea from 1950s to 2010s

a. Changes in surface area of the Aral Sea from 1960 to 2013.

b. The Aral Sea volume decrease from 1957 - 2009



Source: UNEP, 2014.

ESCAP, based on Gaybullaev and others, 2012.

[5] World Meteorological Organization (WMO), (2005). The Aral Sea: Water, climate and environmental change in Central Asia - by Glantz and Zonn. Available at: https://library.wmo.int/doc_num.php?explnum_id=9063.

[6] Gaybullaev, B, Chen. SC, and Kuo, YM, (2012). Large-scale desiccation of the Aral Sea due to over-exploitation after 1960. Journal of Mountain Science volume 9, pp 538–546 (2012). DOI: 10.1007/s11629-012-2273-1.

[7] United Nations Environment Programme (UNEP), (2014). The future of the Aral Sea lies in transboundary co–operation. Available at: https://na.unep.net/geas/getuneppagewitharticleidscript.php?article_id=108.

[8] The National Aeronautics and Space Administration (NASA) MODIS, (2019). October 11, 2019 - The Aral Sea. Available at: https://modis.gsfc.nasa.gov/gallery/individual.php?db_date=2019-10-11.

[9] The National Aeronautics and Space Administration (NASA) Earth Observatory, (2021). World of Change: Shrinking Aral Sea. Available at: https://earthobservatory.nasa.gov/world-of-change/AralSea. Accessed in December 2021.

[10] The National Aeronautics and Space Administration (NASA) Earth Data. Aral Sea, Kazakhstan and Uzbekistan. Available at: https://earthdata.nasa.gov/worldview/worldview-image-archive/aral-sea-kazakhstan-and-uzbekistan. Accessed in December 2021.

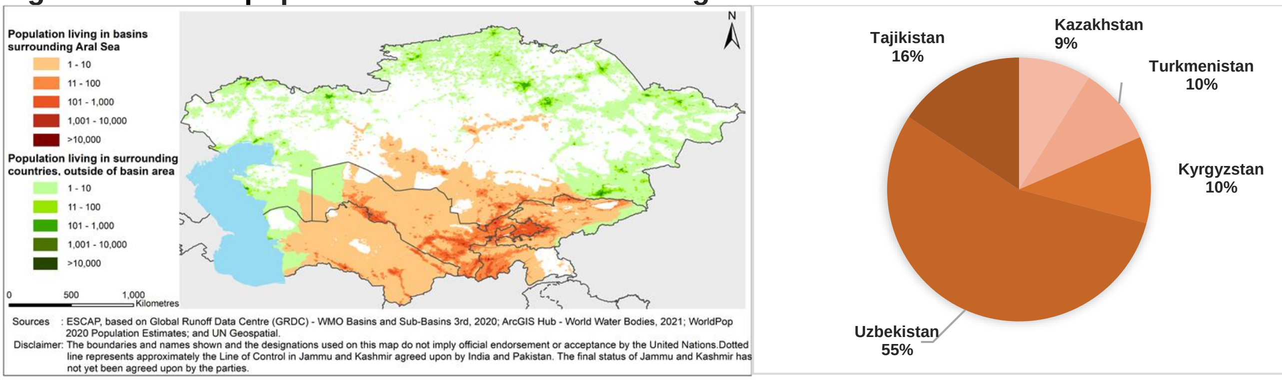
1. Socio-economic and climate profile of Central Asia

The impacts of Aral Sea desiccation is widespread, affecting social and economic life in the subregion. It continues to result in a sharp deterioration in irrigated land, swamping and salinization, declining crop yield, living standards and poor quality of drinking water. Hence, our understanding of the operationalization of the new paradigm of systemic risk management in the Aral Sea context needs to be enhanced. Towards this, ESCAP has undertaken analytical research that brings out a comprehensive economic, social and environmental assessment of the Aral Sea and assesses the latest scientific evidence on the climate crisis using a multi-sectoral and multi-disciplinary approach.

1.3 Population living in basins surrounding Aral Sea

North and Central Asia has a total population of 64 million, of which approximately 51 million (79.2 per cent) live in areas surrounding the Aral Sea basin. The total population in basins surrounding the Aral Sea include that from Uzbekistan (55 per cent), Tajikistan (16 per cent), Kyrgyzstan (10 per cent), Turkmenistan (10 percent), and Kazakhstan (9 per cent) (Figure 1-3).

Figure 1-3 –Total population in basins surrounding the Aral Sea

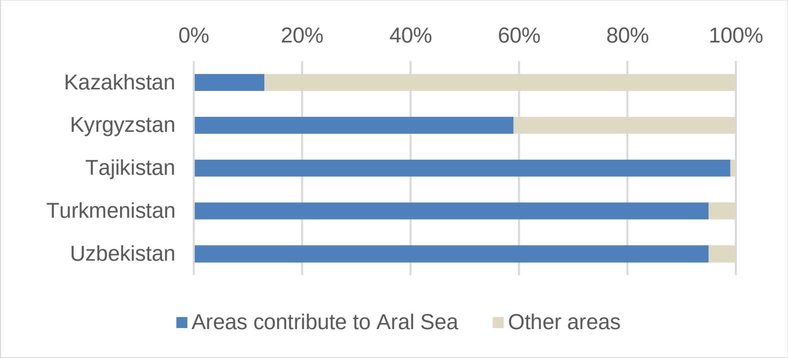


The four river basins surrounding the Aral Sea are 1) Ysyk-Kol (Issyk-Kul), Aral Sea (North), and Syr Darya river basin; 2) Aral Sea (South) and the Amu Darya river basin; 3) Murgap (Murghab), Tejen Dorsay (Harirud) river basin, and 4) Atrek and Karakum basin.[11] Geographically the Aral Sea covers an extensive area of Central Asia, most of Tajikistan (99 per cent), Turkmenistan (95 per cent) and Uzbekistan (95 per cent), Osh, Djalal-Abad and Naryn regions of Kyrgyzstan (59 per cent), Kyzylorda, and South Kazakhstan regions of Kazakhstan (13 per cent) (Figure 1-4).[12]

[11] World Meteorological Organization (WMO), (2020). WMO Basins and Sub-Basins, 3rd ed. (GRDC, 2020). Available at: https://www.bafg.de/GRDC/EN/02_srvcs/22_gslrs/223_WMO/wmo_regions_node.html#:~:text=Hydrologically%2C%20WMO%20Basins%20are%20both,not%20connected%20to%20other%20basins.

[12] Food and Agriculture Organization of the United Nations (FAO), (2012). Transboundary River Basin Overview – Aral Sea. Available at: https://www.fao.org/documents/card/en/c/CA2139EN/.

Figure 1-4 – Proportion of countries' area contributing to the Aral Sea



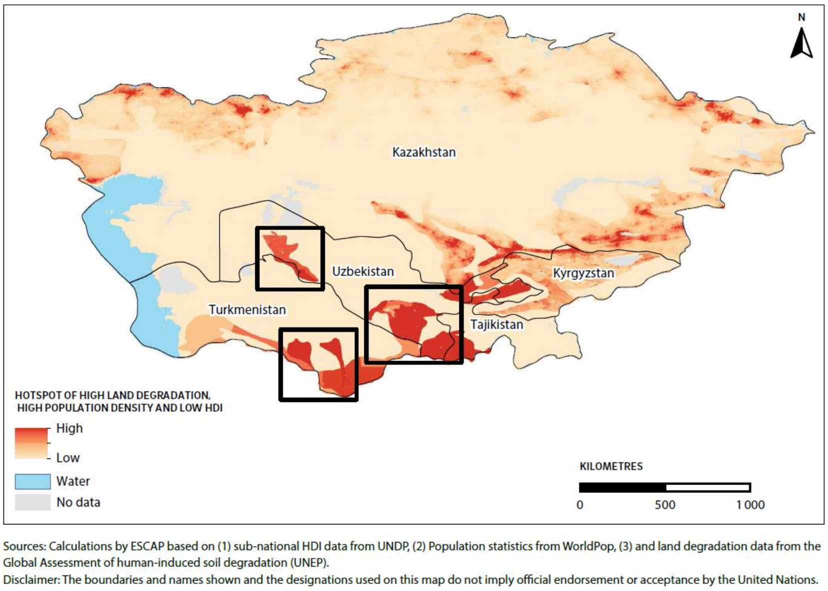
Source: ESCAP based on FAO, 2012.

Vulnerable population living in basins surrounding Aral Sea

Moreover, exposure to disaster risks from the Aral Sea basin intersects with existing vulnerabilities. The vulnerable populations with low-medium HDI are primarily located in Kyrgyzstan, Tajikistan, southern parts of Uzbekistan, and central as well as south-western parts of Turkmenistan. Figure 1-5 identifies the location, where poverty, population density, low human development and disaster risks converge in Central Asia.

In Central Asia, women and children are the most vulnerable groups. Maternal and infant morbidity and mortality are significantly higher in Karakalpakstan and Kyzyl-Orda regions than in other parts of Uzbekistan and Kazakhstan.[13] Due to the severe pollution of all-natural resources in Karakalpakstan Region, the entire population has been chronically exposed to chemicals for a long time. Negative environmental factors (pesticides, high mineralization of water, and elemental imbalances such as iodine deficiency) may also be a major contributor to the development of adverse health consequences for women and children in the Aral Sea region, resulting in a high prevalence of pathologies, including maternal and infant morbidity and mortality.

Figure 1-5 – Hotspots of low Human Development Index and land degradation



Source: ESCAP, 2020.[14]

[13] Ataniyazova O. A., (2003). Health and Ecological Consequences of the Aral Sea Crisis. 18 March 2003. Available at: https://www.caee.utexas.edu/prof/mckinney/ce385d/papers/atanizaova_wwf3.pdf.

[14] United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), (2019). The Disaster Riskscape across North and Central Asia – Key Takeaways for Stakeholders. Available at: https://www.unescap.org/publications/asia-pacific-disaster-report-2019.

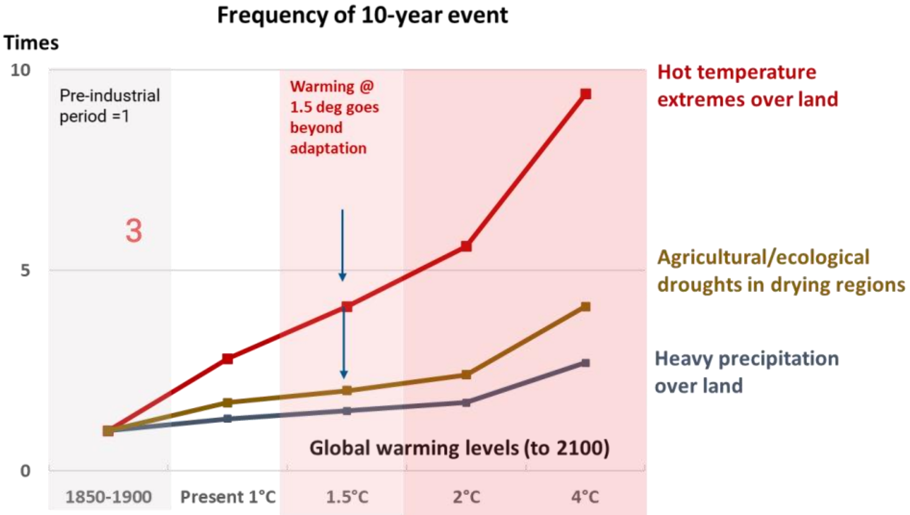
Along the 100 kilometre wide old shoreline of Kazakhstan and Uzbekistan, the impacts of climate change can clearly be seen, due to the shrinkage of the Aral Sea. The impact of climate change extends further with summers becoming warmer, winters becoming colder, delayed spring frosts , fall frost have occurred earlier than usual, decreasing humidity, and shortened growing season. The population living around the sea suffers from acute health problems. Some of these are direct consequences of the sea's recession: respiratory and digestive afflictions; cancer from inhalation and ingestion of blowing salt and dust; and poorer diets from the loss of Aral fish as a major food source.[15] This has also translated in loss of livelihoods, especially for those in heavily impacted industries such as fisheries. The World Bank estimated a 50 per cent decline in fishery outputs between late 2000 and 2004, leading to numerous job losses.[16]

Aridity is the primary constraint limiting the land available for agriculture and livestock production in the Aral Sea basin, where most croplands in Turkmenistan, Uzbekistan, and southern Kazakhstan require irrigation. A United Nations report in 2001 estimated that 46 percent of Uzbekistan's irrigated lands had been damaged by salinity, up from 38 percent in 1982 and 42 percent in 1995. In many instances the crop yields have decreased by half, with some diminishing by as much as two-thirds.[17] Agriculture is also potentially highly vulnerable to climate change due to the degradation of limited arable land and a scarcity of irrigation water.

1.2 Climate change in Central Asia - Projected changes in extremes

Climate change creates a cycle of existential degradation whereby human activity adversely impacts climate change which in turn restricts and adversely affects the population. Based on the IPCC Sixth Assessment Report, the difference between 1.5 and 2 degrees is substantial: every increment of a degree translates into increased risks as shown in Figure 1-7. In Central Asia particularly, there have been observed changes in hot extremes as well as in agricultural and ecological drought. These changes have been exacerbated by human influence.[18]

Figure 1-7 – Projected Changes in Extremes



Source: ESCAP based on IPCC Sixth Assessment Report

[15] Micklin P., Aladin N.V., Plotnikov I., (2014). The Aral Sea - The Devastation and Partial Rehabilitation of a Great Lake. Available at: https://link.springer.com/book/10.1007/978-3-642-02356-9.

[16] United Nations Environment Programme (UNEP), (2014). The future of the Aral Sea lies in transboundary co–operation. Available at: https://na.unep.net/geas/getuneppagewitharticleidscript.php?article_id=108.

[17] Thompson, (2008). The Aral Sea Crisis. Available at: http://www.columbia.edu/~tmt2120/introduction.htm.

[18] Intergovernmental Panel on Climate Change (IPCC), (2021). The Sixth Assessment Report on The Physical Science Basis. Available at: https://www.ipcc.ch/report/ar6/wg1/.

The climate model "Coupled Model Intercomparison Projects" (CMIP6) presents new scenarios with greater certainty of the emerging climate risk. It has brought out one of the critical links between policy action and climate change with the socioeconomic pathways (SSPs). This CIMP6 data has projected the increase in annual mean temperature under SSP2-4.5 (or scenario with intermediate GHG emissions) until the next 20 years in Central Asia ranges from 0.81°C to 2.86°C, and from 0.98°C to 3.46°C under SSP3-7.0 (or scenario with high GHG emissions) until the next 20 years.[19] The time frame chosen are Near (2021-2040) and Long (2081-2100) term.

Climate change will impact the various communities of Central Asia differently. As mentioned in *the IPCC Sixth Assessment Report on Impacts, Adaptation and Vulnerability*, the glacier and snow mass loss will impact water security and livelihood.[20] It is predicted that the annual run-off water in one-third of the large-scale glacier areas will experience more than 10 per cent decline by 2100, with one of the most significant reductions of this sort taking place in Central Asia.

The unsustainable land-use and land cover change effects human capacity to adapt to climate change globally.[21] There has been increasing evidence that ecosystem degradation by humans increases human vulnerability to adapt to climate change. IPCC also identifies land cover change in Central Asia from 1990 to 2021, such as the increased woody and shrub cover in arid deserts and grasslands.

Intensifying agricultural and ecological drought risk

The following datasets were downloaded from the IPCC WGI Interactive Atlas and used as indicators in present study of drought risk in the Aral Sea region. The supporting maps depict the future projections of the respective indicators under SSP2 and SSP3 near and long-term scenarios. The graphs that follow show the minimum, maximum and mean trends of these indicators under different pathways and time periods.

Temperature rise

The temperature in Central Asia region has been increasing rapidly since 1997.[22] Based on the CIMP6 data, Figure 1-8 depicts the projected annual mean temperature change in °C for moderate (SSP2) and worst-case (SSP3) scenarios. The selected time frames are Near term (2021-2040) and Long term (2081-2100). As illustrated, the highest temperature increase is going to be around 1.29°C to 1.31°C for the near term moderate scenario in the norther parts of Kazakhstan. However, under long term worst-case scenario, the area of exposure expands to the whole region with the highest temperature increase around 3.52°C to 5.42°C.

Figure 1-9. shows that the Projected average increase of annual mean temperature under SSP2 near-term to SSP3 long-term is between 1.12°C to 4.66°C in Central Asia. The maximum temperature rise is between 1.32°C to 5.42°C while the minimum is between 0.85°C to 3.41°C. This indicates that due to global warming, more regions and people will be exposed to greater risks.

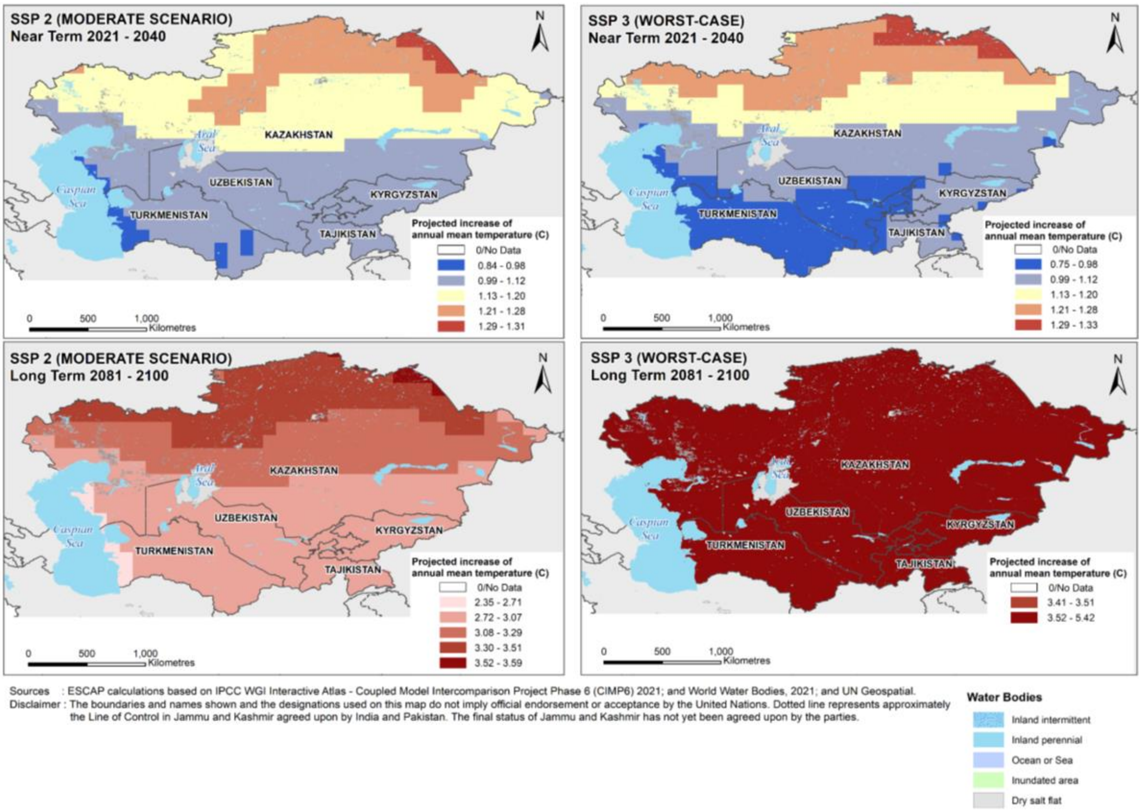
[19] ESCAP calculations, based on IPCC WGI Interactive Atlas – CMIP6 data, 2021.

[20] IPCC, (2022). The Sixth Assessment Report on Impacts, Adaptation and Vulnerability - Technical Summary. Available at: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf.

[21] IPCC, (2022). The Sixth Assessment Report on Impacts, Adaptation and Vulnerability. Available at: https://www.ipcc.ch/report/ar6/wg2/.

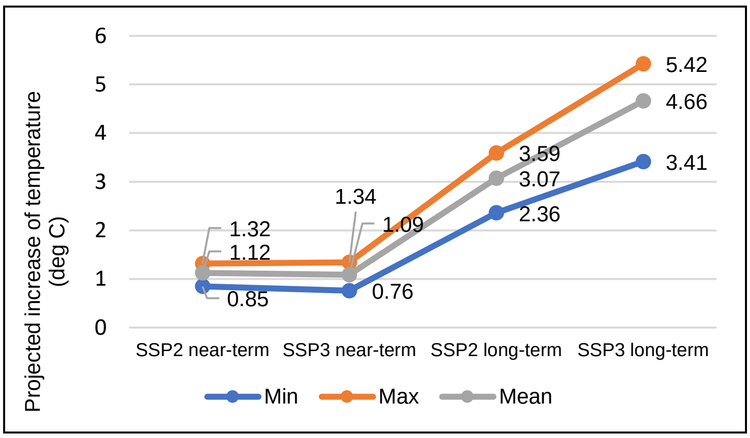
[22] IPCC, (2022).

Figure 1-8 – Projected increase of annual mean temperature (unit: °C) under SSP2 (moderate) and SSP3 (worst-case) scenarios, near term 2021-2040 and long-term 2081-2100



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021; and World Water Bodies, 2021; and UN Geospatial.
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Figure 1-9 – Projected increase of annual mean temperature (deg C)



Increase in number of dry days

An increase in the number of dry days could contribute to agricultural drought and heatwaves. Figure 1-10 depicts the projected increase in annual consecutive dry days for moderate (SSP2) and worst-case (SSP3) scenarios. The western parts of the region (around Caspian and Aral Sea) like western Kazakhstan, Turkmenistan and Uzbekistan will experience maximum increase in consecutive dry days with the range being 6 to 13 days under near term moderate scenario and the area of exposure expanding to the central parts of the region under the long term worst-case scenario with a range of 6 to 14 days. Figure 1-11 shows that the projected average increase of annual consecutive dry days under SSP2 near-term to SSP3 long-term is between 2 to 4 days in Central Asia. The maximum consecutive dry days increase ranges from 12 to 14 days while the minimum is 0 to 0.1 days.

Figure 1-11 shows that the projected average increase of annual consecutive dry days under SSP2 near-term to SSP3 long-term is between 2 to 4 days in Central Asia. The maximum consecutive dry days increase ranges from 12 to 14 days while the minimum is 0 to 0.1 days.

Figure 1-10 – Projected change (increase) of annual consecutive dry days (unit: number of days)

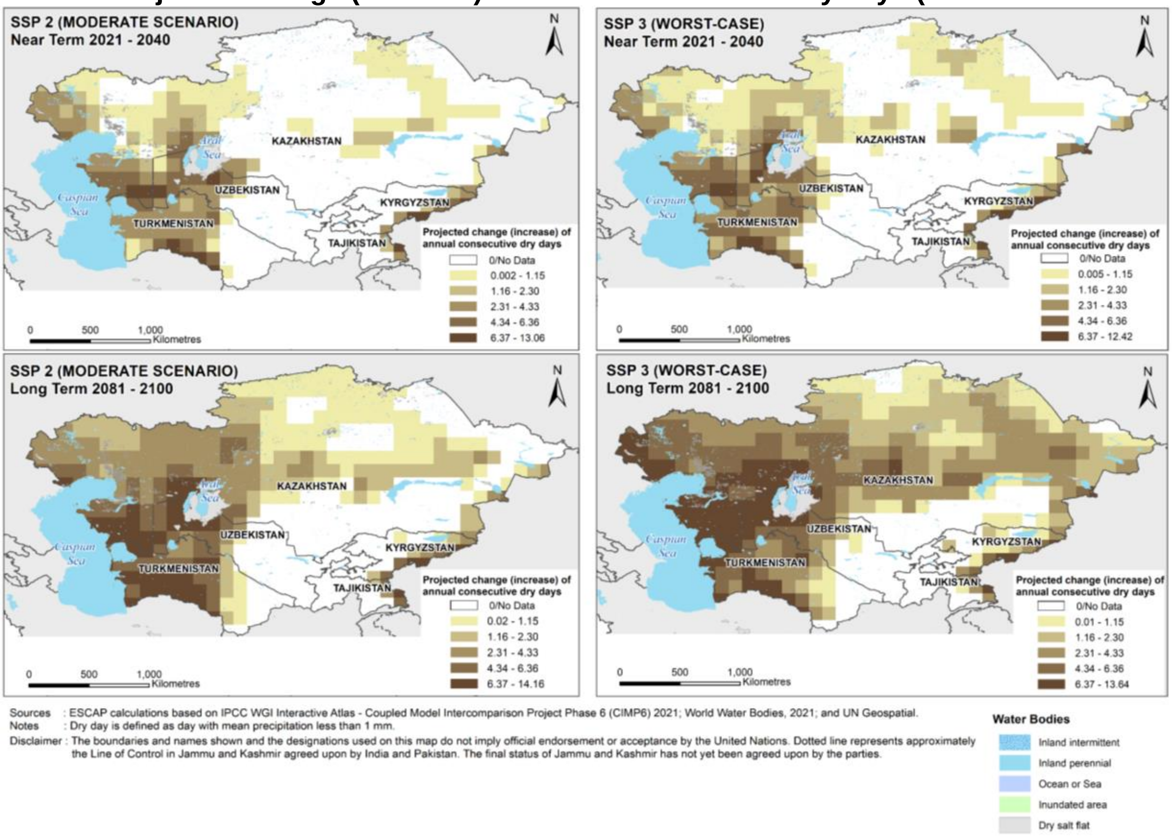
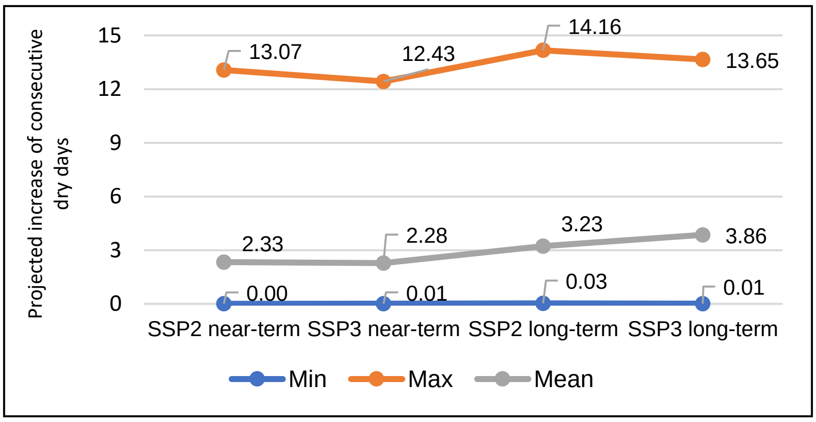


Figure 1-11 – Projected change (increase) of annual consecutive dry days (unit: days)



Decrease in precipitation during dry months

Another factor that contributes to agricultural drought and heatwaves is a decrease in precipitation. As time progresses, the region will experience a maximum of 3.85% to 5.05% percentage decrease in precipitation in the north-western and north-eastern parts of Kazakhstan. The area of exposure is also intensifying and expanding to the south-eastern (Tajikistan and Kyrgyzstan) and south-western parts of the region (Turkmenistan) with the range being 3.85% to 16.21% decrease. Figure 1-12 depicts the projected percent decrease of maximum 5-day cumulative precipitation during the dry months of the region for moderate (SSP2) and worst-case (SSP3) scenarios. The time frame chosen are Near (2021-2040) and Long (2081-2100) term.

Figure 1-13 shows that the projected average decrease of maximum 5-day precipitation in June-August under SSP2 near-term to SSP3 long-term is between 1.66 to 4.49 mm in Central Asia. The maximum decrease of maximum 5-day precipitation in June-August ranges from 5.05 to 16.22 mm. The minimum is between 0.03 to 0.10 mm.

Figure 1-12 – Projected per cent decrease of maximum 5-day precipitation during the dry months (June - August) (Unit: %)

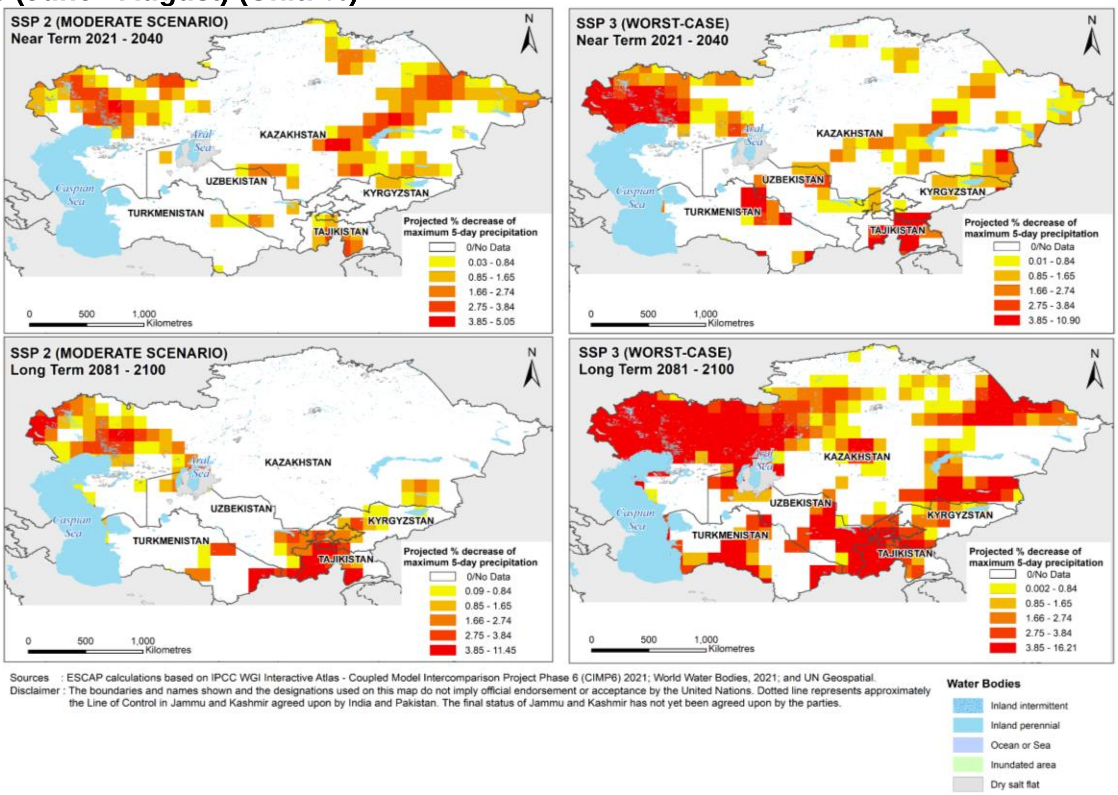
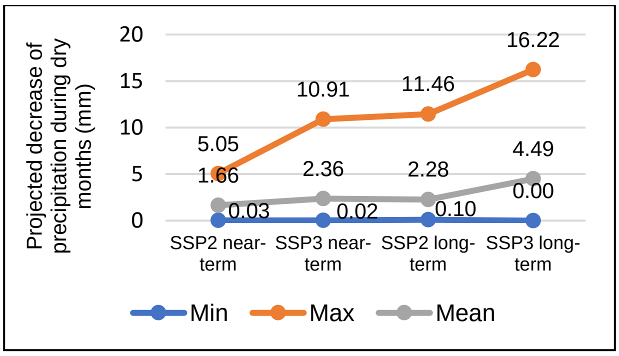


Figure 1-13 – Projected decrease of maximum 5-day precipitation (mm) during the dry months (June - August)

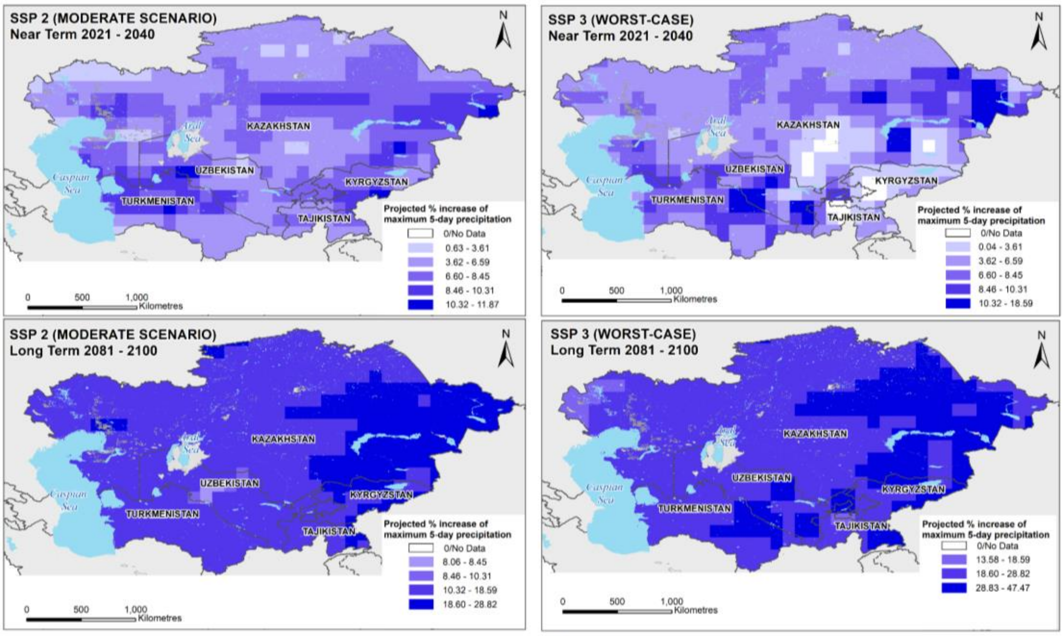


Increase in precipitation during the wet months

The region will experience decreased precipitation throughout most of the year, especially during dry months. However, during the high precipitation season between December and February, there will be an increase in rainfall. The maximum percentage increase of 10.32% to 11.87% under near term moderate scenario is experienced by some parts of the region but this expands, intensifies and shifts towards the eastern (Kazakhstan, Kyrgyzstan and Tajikistan) and southern (Uzbekistan and Turkmenistan) parts of the region with maximum percentage increase of 25.83% to 47.47%. Figure 1-14 depicts the projected percent increase in maximum 5-day cumulative precipitation during the wet months of the region for moderate (SSP2) and worst-case (SSP3) scenarios. The time frame chosen are Near (2021-2040) and Long (2081-2100) term.

Figure 1-15 shows that the projected average increase of maximum 5-day precipitation in December to February under SSP2 near-term to SSP3 long-term is between 6.59 mm to 26.64 mm in Central Asia. The maximum increase of maximum 5-day precipitation during these months ranges from 11.88 mm to 47.47 mm while the minimum ranges from 0.63 mm to 13.59 mm.

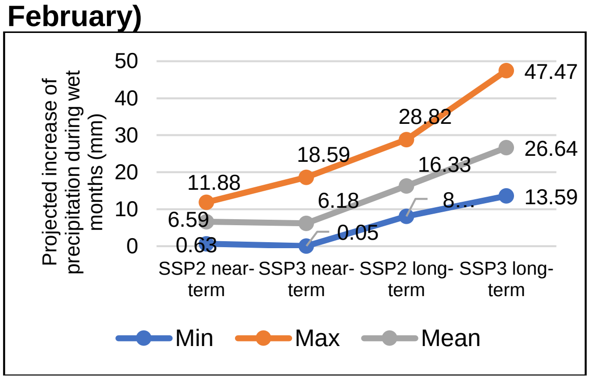
Figure 1-14 – Projected % increase of maximum 5-day precipitation (mm) during high precipitation season (December – February) (Unit: %)



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021; World Water Bodies, 2021; and UN Geospatial.
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Water Bodies
Inland intermittent
Inland perennial
Ocean or Sea
Inundated area
Dry salt flat

Figure 1-15 – Projected increase of maximum 5-day precipitation(mm) during season with high precipitation (December – February)



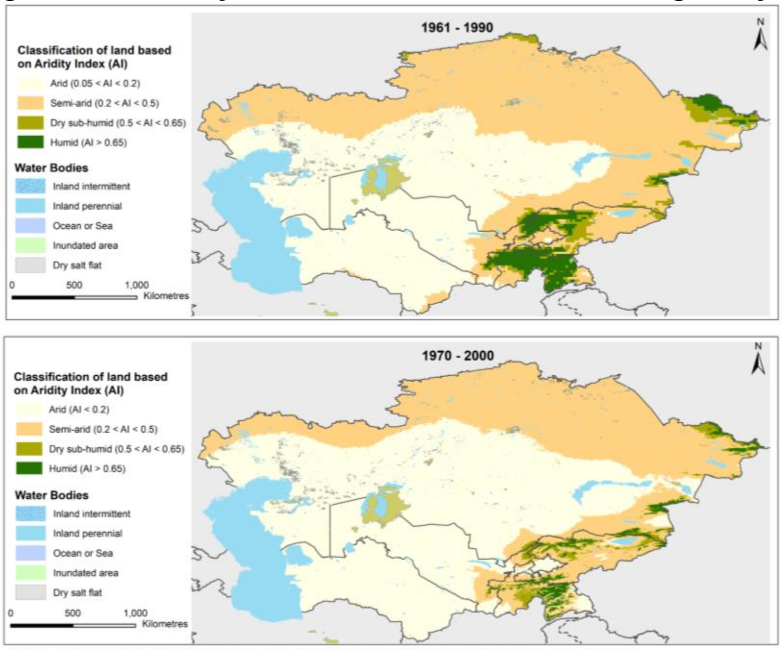
1.3 Under future climate scenario, the extent of drylands is projected to expand

Aridity is a climate phenomenon principally characterized by a shortage of water. It is commonly quantified by comparing long-term averages of water supply or precipitation (P) to long-term averages of climatic water demand (known as potential evapotranspiration). Potential evapotranspiration (PET) is a measure of the atmosphere's "drying power" in terms of removing water from land surfaces via evaporation (e.g., from the soil and plant canopy) and transpiration by plants. The Aridity Index (AI) is a straightforward but convenient numerical aridity indicator calculated as the ratio P/PET. The AI is a widely used indicator of a climate's dryness at a given location.[23]

Arid and semi-arid regions have been expanding and intensifying in North and Central Asian countries of Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, and Tajikistan. The comparison of the two thirty-year periods, 1961-1990 and 1970-2000, in Figure 1-16, shows Arid areas expanding into previously semi-arid regions of northern Kazakhstan and western Uzbekistan and dry sub-humid and humid areas of Tajikistan, Kyrgyzstan and eastern, north-central Kazakhstan have become arid and semi-arid over a decade. Arid lands are subject to different climate-related erosion processes, enhancing land degradation and desertification risk.[24]

Under the future climate scenarios, drylands are projected to expand further in many parts of the world as a consequence of precipitation anomalies, increase in temperature, potential evapotranspiration (PET), and decrease in soil moisture.[25] Intensifying aridity and drought may also affect food security, human health and nutrition. Irrigation with mineralized groundwater also increases soil salinity and decreases crop productivity.

Figure 1-16 – Changes in the aridity in Central Asia observed through 40-year time period



Sources : ESCAP, based on Map of Aridity, FAO, 2009; The Global Aridity Index Version 2, 2019; World Water Bodies, 2021; and UN Geospatial.
Note : The Aridity Index classification is based on generalized climate classification scheme for Aridity Index values (UNEP 1997).
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

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[23] Hill J. , Von Maltitz G. , Sommer S. , Reynolds J. , Hutchinson C. , Cherlet M., (2018). European Commission, Joint Research Centre, World atlas of desertification: rethinking land degradation and sustainable land management. Available at: https://data.europa.eu/doi/10.2760/9205.

[24] Nkonya E. , Mirzabaev A. , Braun J. V. , (2016). Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Available at: https://link.springer.com/book/10.1007/978-3-319-19168-3.

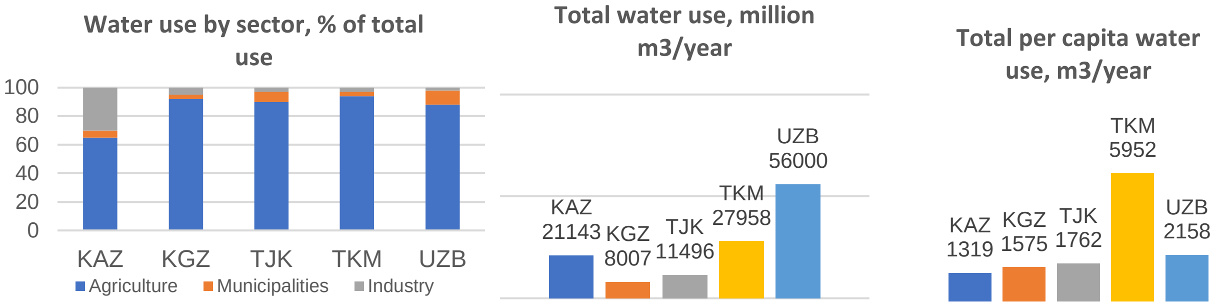
[25] Hill J. , Von Maltitz G. , Sommer S. , Reynolds J. , Hutchinson C. , Cherlet M., (2018). European Commission, Joint Research Centre, World atlas of desertification: rethinking land degradation and sustainable land management. Available at: https://data.europa.eu/doi/10.2760/9205.

1.4 Water and agriculture in Central Asia

Water is one of the human basic necessities. Other forms of basic necessities such as energy and food security are interlinked with water. According to FAO, Central Asia is a region with the greatest water withdrawals per capita in the world, reaching almost 2,000 m^3 per person in 2025.[26]

Water use in central Asian countries is dominated by the agriculture sector, accounting for more than 65 per cent of the total water use in the region.[27] Uzbekistan has the greatest annual water use at 56,000 million m^3, followed by Turkmenistan at nearly 28,000 m^3.

Figure 1-17 – Water use in Central Asia



Source: European Parliamentary Research Service (2018).

Share of croplands and water use

Dryland agriculture is the dominant type of agriculture in Central Asia. The dry savanna agriculture, desert and dry rangeland are widely located around Tajikistan, Uzbekistan, Turkmenistan, Kazakhstan and Kyrgyzstan. In **rain-fed agriculture** found in semi-arid and arid regions, water is the most limiting factor due to its dependency on rain. Additional sources of water are necessary in case of lack of rainfall.[28] Irrigation systems can help to solve this problem, however, the sources of water are very limited. Moreover, globally, dryland agriculture is dominated by small-scale and resource poor farmers who many have limited access to alternative water sources.[29]

The rainfed land in Central Asia comprises more than 30 per cent low-input[30] rainfed with high to very high drought frequency, more than 20 per cent are low-input rainfed from low to medium drought frequency, and around 10 per cent are high-input[31] rainfed from low to very high drought frequency.

[32] **Hence, more than 50 per cent of rainfed land is low-input agriculture which is vulnerable to climate change due to its reliability on human and livestock labor.**

Based on ESCAP calculation on NASA's Global Food Security Support Analysis Data (GFSAD) Crop Mask 2010 Global, around four-fifths of Central Asia's cropland is rainfed land. Figures 1-18 and 1-19 illustrate the location and proportion of irrigated and rainfed agriculture.

As economies of some countries in the region rely heavily on the agriculture sector, it contributes

[26] Food and Agriculture Organization of the United Nations (FAO), (2020). State of Food and Agriculture 2020. Available at: https://www.fao.org/documents/card/en/c/cb1447en/#:~:text=The%20State%20of%20Food%20and%20Agriculture%202020%20presents%20new%20estimates,the%20number%20of%20people%20affected.
[27] European Parliamentary Research Service, (2018). Water in Central Asia - an increasingly scarce resource. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/625181/EPRS_BRI(2018)625181_EN.pdf.
[28] Food and Agriculture Organization of the United Nations (FAO), (2016). State of Food and Agriculture 2016. Available at: https://www.fao.org/family-farming/detail/en/c/447860/.
[29] FAO, (2020).
[30] High-input rainfed land are rainfed agriculture land that grows market-oriented crops.
[31] Low-input rainfed land are rainfed agriculture land which rely on available human or livestock labour.
[32] FAO, (2020).

heavily to the GDP of the region. For example, the share of agriculture accounts for 25.1 per cent of the GDP in Uzbekistan and 23.8 per cent of the GDP in Tajikistan.[33]

Figure 1-19 illustrates the shares of irrigated and rainfed cropland in Central Asian countries. In Kazakhstan, there is approximately 650 km^2 rainfed land, which is 7 times higher than the irrigated land. In Kyrgyzstan, the rainfed land is 76 km^2 or 7.5 times the size of irrigated land. In Tajikistan, there is 36 km^2 rainfed land or 6 times the size of irrigated land. On the contrary, Turkmenistan has smaller proportion of rainfed land compared to the irrigated land, which is 17 km^2 or 63 per cent of its irrigated land. Indeed, the irrigated land relies more on water from the irrigation system. The expansion of irrigated agriculture in the Aral Sea basin has contributed to the increasing salinity of the ground water, which may result in decreasing crop yields. It is estimated that by now, more than half of the irrigated soils in Central Asia are saline.[34] In addition, the projected climate change impacts on agriculture can pose a serious threat to food security in the region.

Figure 1-18 – Proportion of irrigated and rainfed agriculture

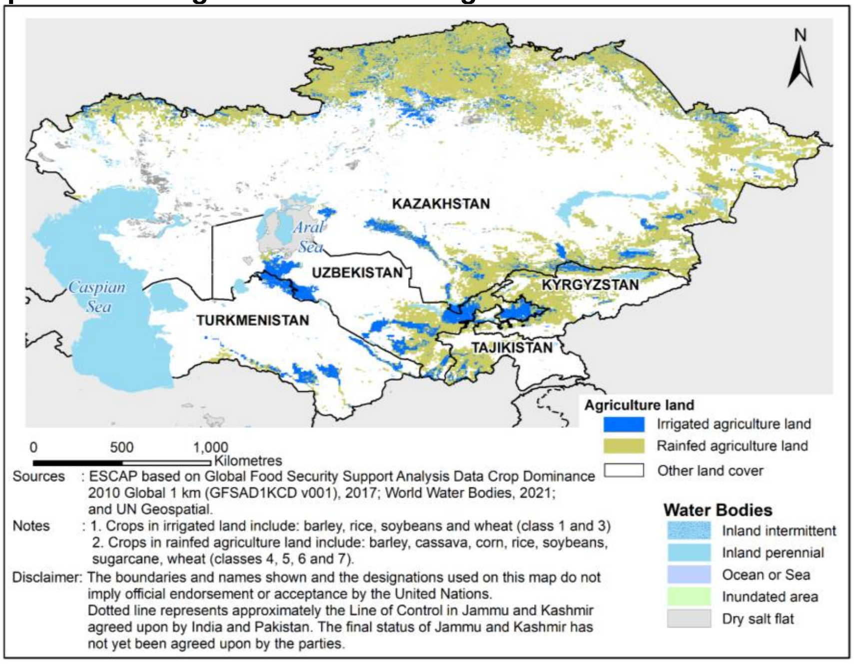
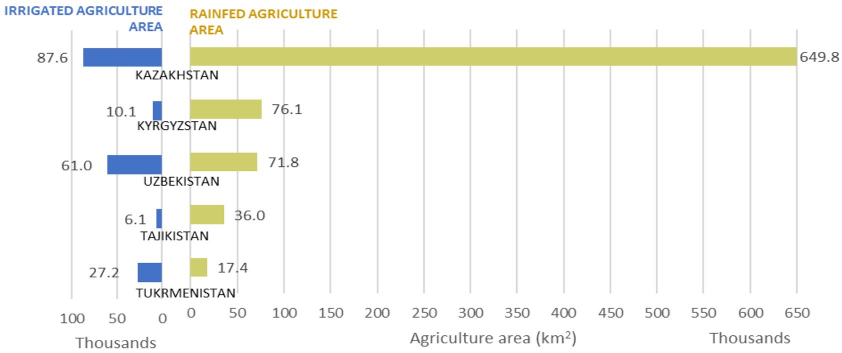


Figure 1-19 – Proportion of irrigated and rainfed agriculture



Source: ESCAP calculations, based on Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001) 2017.

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[33] World Bank, (2020). Agriculture, forestry, and fishing, value added (% of GDP). Available at: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=TJ and https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=UZ.

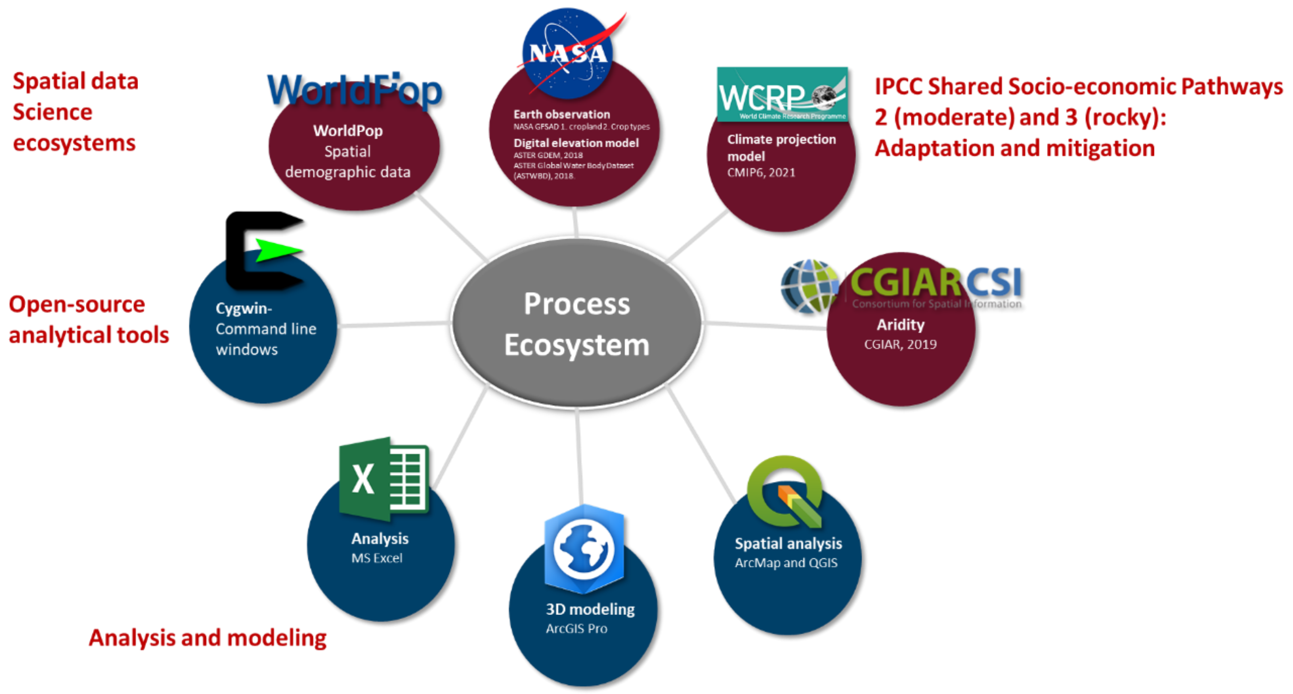
[34] Qadir M., Noble A. D., Qureshi A. S., Gupta R. K., Yuldashev T., and Karimov A., (2009). Salt-induced land and water degradation in the Aral Sea basin: A challenge to sustainable agriculture in Central Asia. Natural Resources Forum Volume 33, Issue2. May 2009, pp 134-149. Available at: https://doi.org/10.1111/j.1477-8947.2009.01217.x.

2. Agriculture land exposure to multi-criteria indicators for climate and aridity in basins surrounding Aral Sea

A framework to assess the agriculture land exposure to climate and environmental risk has been developed. It consists of multi-criteria datasets and software to process the risk analytics as shown in Figure 2-1. The multi-criteria datasets are derived from a) the World Climate Research Programme, namely the CIMP6 climate data under moderate scenario (SSP2) and worst-case scenario (SSP3), near-term (2021-2040) and long-term (2081-2100); b) Aridity index from the Consultative Group for International Agriculture Research (CGIAR); c) Spatial data science ecosystem – WorldPoP spatial demographic data and d) NASA's Earth Observation – Global Food Security Support Analysis Data Crop Dominance (GFSAD) (2017) – Crop land and crop types, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) with 30 m resolution data.

To process the analysis and develop the models, spatial analysis such as 3D modeling ArcGIS Pro and QGIS, and MS Excel has been used. In addition, open-source analytical tools – Cygwin that provides functionalities like linux which enables access to large number of granules for ASTER GDEM, Global Water Body Datasets (ASTEWBD) and GFSAD 30 m crop land dataset from NASA Earth data have been used.

Figure 2-1 – Analytical framework of ESCAP Climate change study of Aral Sea



2.1 Agriculture land exposure to multi-criteria indicators related to drought under SSP2 scenario, near-term and SSP3 scenario, long-term

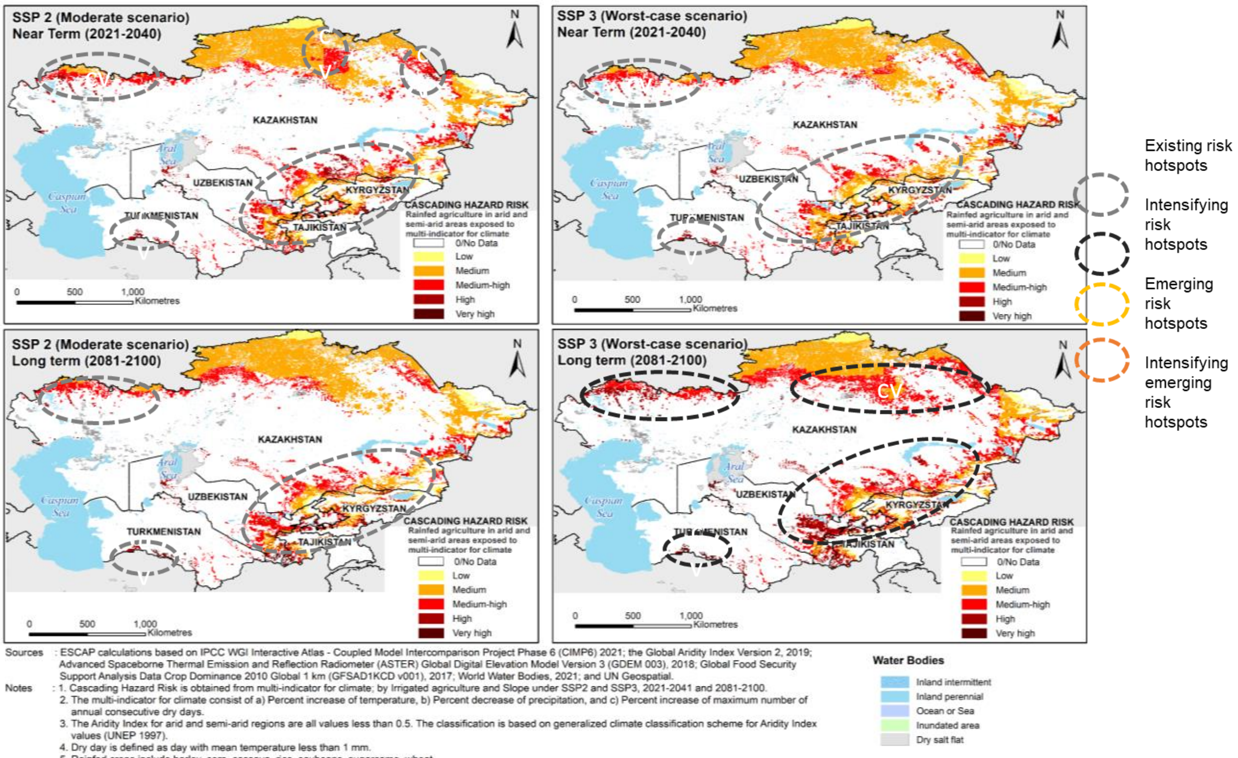
The potential agriculture exposure to drought has been estimated using a set of multi-criteria indicators. These indicators comprise 1) aridity, 2) projected climate-related indices, 3) slope. The climate-related indices consist of decrease in rainfall, increasing number of dry days and temperature. Once processed, these data are overlaid on agriculture land area and the exposure areas have been calculated. These outputs are also processed on a DEM model to get 3-dimensional images. By identifying the exposure and potential impacts of climate change on agriculture under future scenarios, as well as the contributing factors, adaptation measures have been prepared. The output of this research is multiple scenarios of agriculture exposure to multi-criteria indicators for climate related hazard, from SSP2 (moderate) near and long-term scenarios, and SSP3 (worst-case) near term and long term scenarios. The details of methodology are available in Methodology Annex.

Hotspots of rainfed cropland exposure to drought, aridity and climate change will intensify and expand over time-periods and scenarios.

Under SSP2 (moderate) near-term (2021-2040) scenario, the rainfed cropland risk hotspots exist around 1) North-west of Kazakhstan; 2) North-central of Kazakhstan; 3) North-east of Kazakhstan; 4) south of Turkmenistan; and in the south-eastern parts of the region 5) south-central and south-east of Kazakhstan, north, central and west of Kyrgyzstan, south-west of Tajikistan and south-east of Uzbekistan as shown in Figure 2-2 and in Figure 2-3 as three-dimensional images. The three-dimensional images better illustrate the risk and topography, in which the south-eastern and eastern parts of the region are mountainous areas.

Under SSP3 (worst-case) long-term (2081-2100) scenario, all the former hotspots will intensify and expand. Significant expansion of risk-hotspots category high to very high are seen around north-central to north-east of Kazakhstan.

Figure 2-2 – Hotspots of Rainfed agriculture exposure to drought

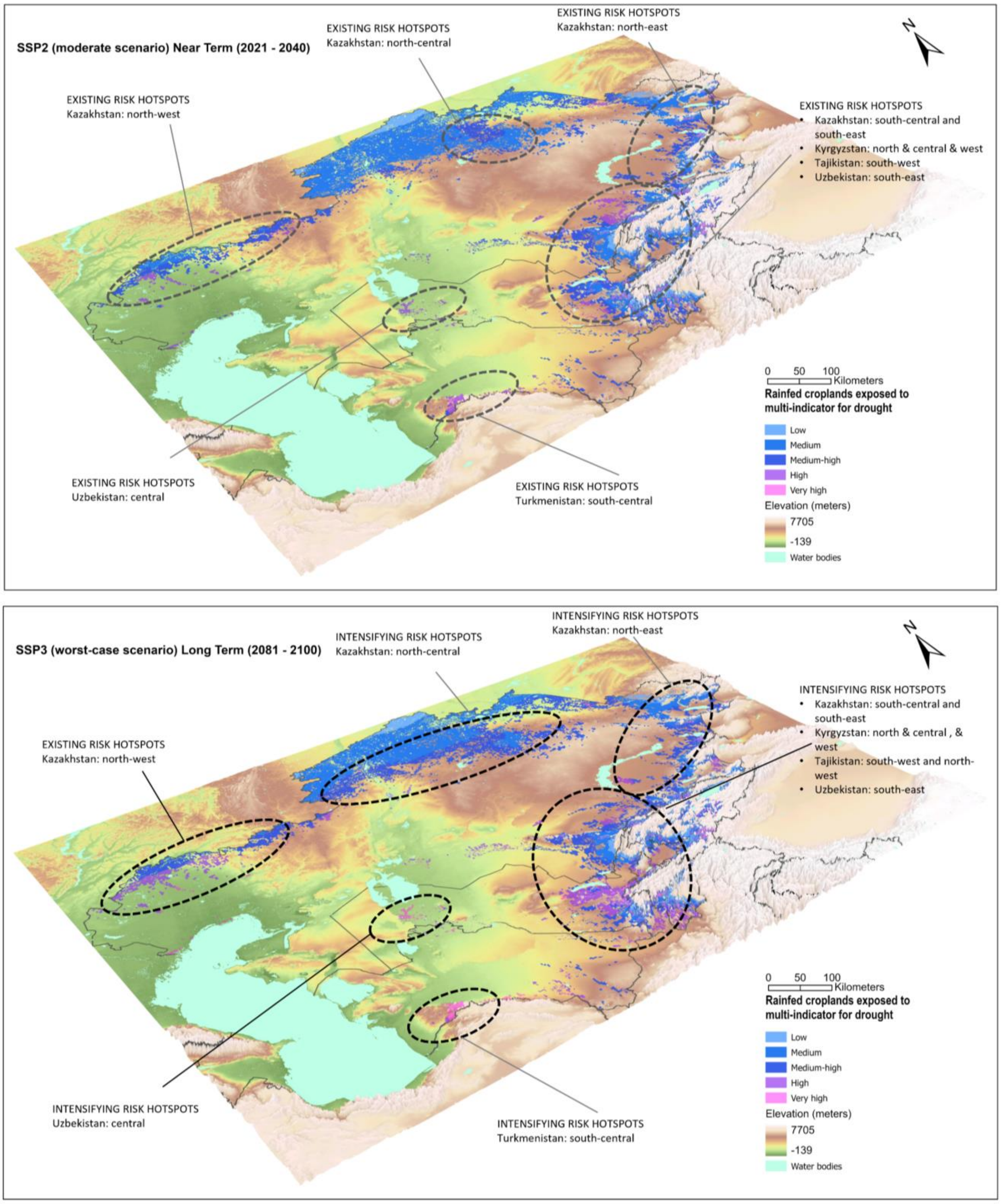


Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021; the Global Aridity Index Version 2, 2019; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003), 2018; Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001), 2017; World Water Bodies, 2021; and UN Geospatial.

Notes : 1. Cascading Hazard Risk is obtained from multi-indicator for climate; by Irrigated agriculture and Slope under SSP2 and SSP3, 2021-2041 and 2081-2100.
2. The multi-indicator for climate consist of a) Percent increase of temperature, b) Percent decrease of precipitation, and c) Percent increase of maximum number of annual consecutive dry days.
3. The Aridity Index for arid and semi-arid regions are all values less than 0.5. The classification is based on generalized climate classification scheme for Aridity Index values (UNEP 1997).
4. Dry day is defined as day with mean temperature less than 1 mm.
5. Rainfed crops include barley, corn, cassava, rice, soybeans, sugarcame, wheat.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Figure 2-3 – 3D visualization of Hotspots of Rainfed agriculture exposure to drought under SSP2 near-term and SSP3 long-term scenarios



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CMIP6) 2021;the Global Aridity Index Version 2, 2019; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003),2018; Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001) 2017; World Water Bodies, 2021; and UN Geospatial.

Notes : 1. The multi-indicator for climate consist of a) Increase in temperature (°C) b) Percent decrease in precipitation, and c) Increase in maximum number of annual consecutive dry days.
2. The Aridity Index for arid and semi-arid regions are all values less than 0.5. The classification is based on generalized climate classification scheme for Aridity Index values (UNEP 1997).
3. Dry day is defined as day with mean precipitation less than 1 mm.

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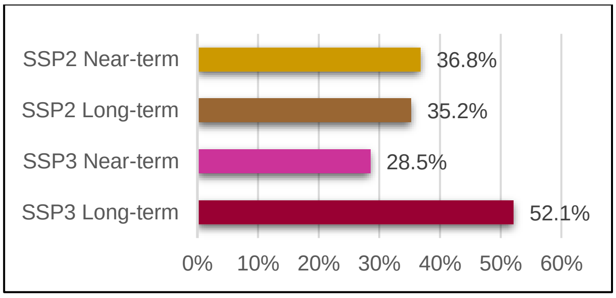
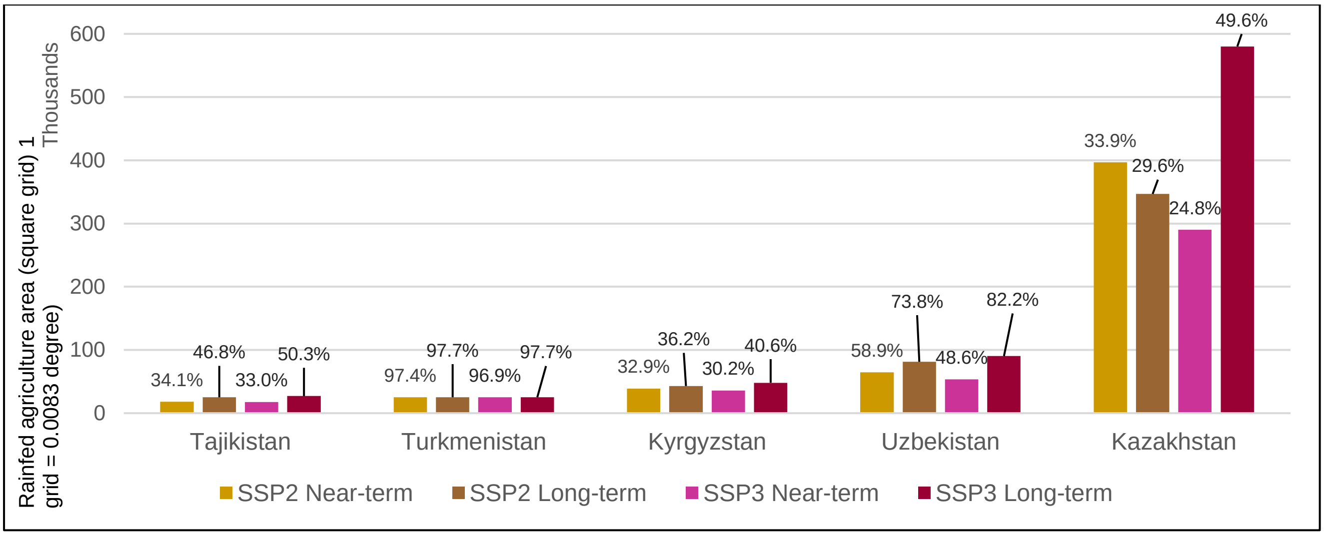
Figure 2-4 – Shares of rainfed agriculture land exposure to multi-indicator for drought under SSP2 and SSP3 scenarios, near-term and long-term (medium-high to very high risk categories)



Rainfed agriculture comprises 82 per cent of the total agriculture in Central Asia. From the total 851 km^2 rainfed cropland, 36.8 per cent will be exposed to drought under SSP2 (moderate) near-term (2021-2040) scenario. The exposure will increase to 52.1 per cent under SSP3 (worst-case) long-term (2081-2100) scenario (Figure 2-4).

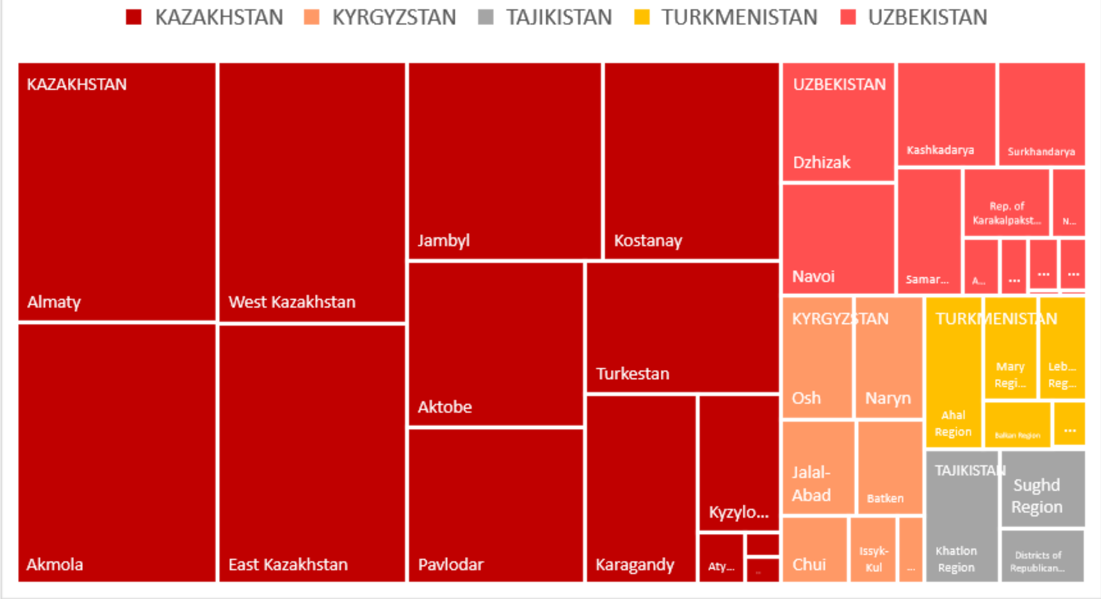
Kazakhstan on average has the highest rainfed cropland exposure to drought under climate scenarios, accounting for more than 40 per cent of the total regional land exposure. Under SSP3 long-term scenario, this exposure is equal to 49.6 per cent of the total rainfed land in Kazakhstan. On the contrary, even though Turkmenistan shares less than 20 per cent of rainfed land exposure to drought in the entire region, this 20 per cent makes up around 97 to 98 per cent of the total rainfed land area in Turkmenistan.

Figure 2-5 – Rainfed agriculture land exposed to multi-indicator for climate under SSP2 (moderate) and SSP3 (worst case), near term 2021-2040 and long term 2081-2100 scenarios - medium-high to very high risk categories[35]



[35] One square grid unit in this report equals to 1 km^2 at the equator.

Figure 2-6 – Subnational level of Rainfed agriculture areas average exposure to multi-criteria indicators for drought under SSP2 and SSP3, near and long-term scenarios category medium-high to very high risk



The total exposures at subnational level can be seen in Figure 2-6. The square size shows the size of the area exposed to drought. The regions of Almaty, Akmola, West Kazakhstan and East Kazakhstan are regions with the largest exposure to medium-high to very high risk of drought.

The hotspots of rainfed agriculture land exposed to drought under SSP3 long-term scenarios are located in the following areas: 1. North-west of Kazakhstan (West Kazakhstan Region); 2. North-central of Kazakhstan (Akmola Region); 3. North-east of Kazakhstan (East Kazakhstan); 4. south of Turkmenistan (Ahal Region); and 5. in the south-eastern parts of the region: south-central (Jambyl Region) and south-east of Kazakhstan (Almaty Region), north and central (Naryn Region) and west (Osh, Jalal-Abad, Batken Region) of Kyrgyzstan, south-west (Khatlon Region) and north-west (Sughd Region) of Tajikistan, and south-east of Uzbekistan (regions of Dzizhak, Kashkadarya, Surkhandarya and Samarkand).

Hotspots of irrigated land exposure to drought, aridity and climate change will intensify and expand over time-periods and scenarios

Under SSP2 (moderate scenario) near-term 2021-2040, the risk hotspots exist around 1) north-west of Kazakhstan, 2) south of Kazakhstan, 3) the neighboring areas of north and west Kyrgyzstan, south-west Tajikistan, south-east parts of Uzbekistan, and south-east parts of Turkmenistan, 4) south-west of Uzbekistan and central-north of Turkmenistan, and 5) central-south of Turkmenistan, as shown in Figure 2-7.

The hotspot of the south Kazakhstan and the neighboring areas of north and west Kyrgyzstan, south-west Tajikistan, south-east parts of Uzbekistan, and south-east parts of Turkmenistan hotspots will be intensifying under the SSP3 (worst-case) long-term (2081-2100) scenario. The emerging hotspots around north-central parts of Kazakhstan which appeared under SSP2 (moderate) long-term scenario will also intensify under SSP3 (worst-case) long-term scenario.

Figure 2-7 – Hotspots of Irrigated agriculture exposure to drought

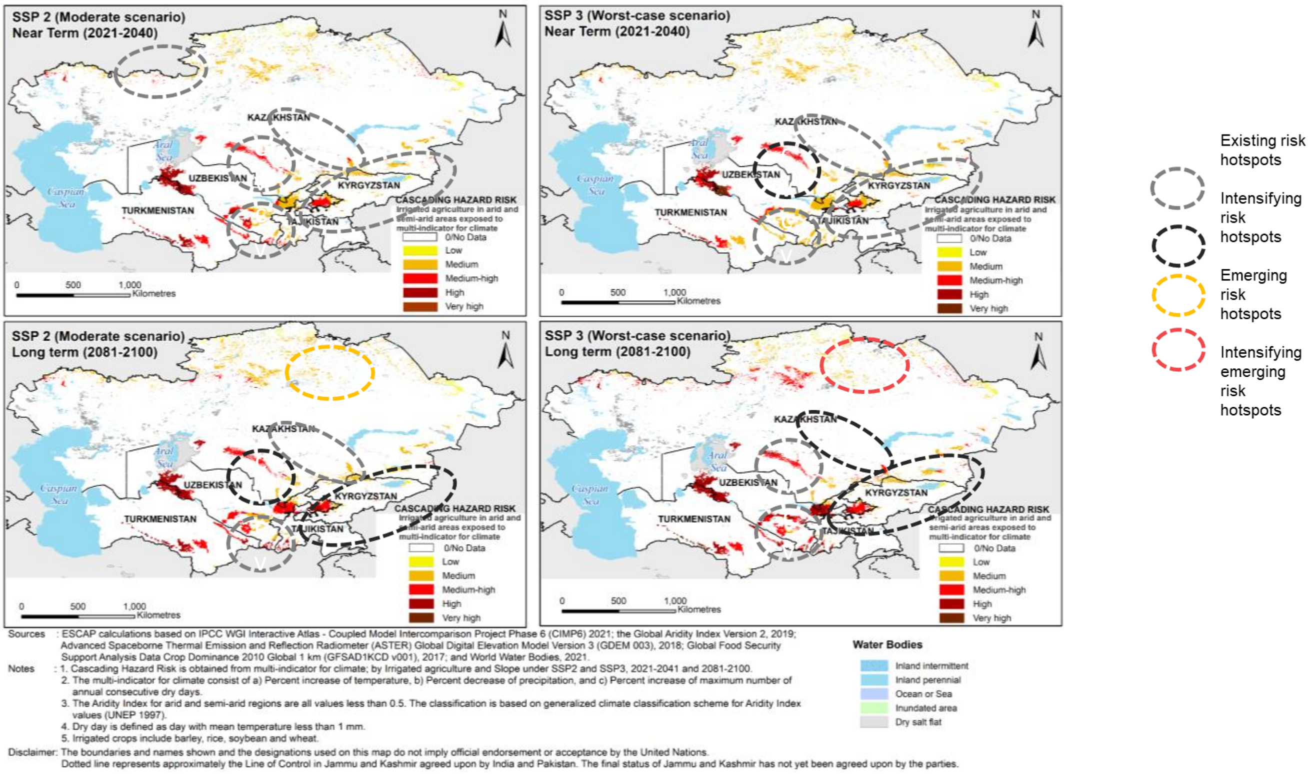
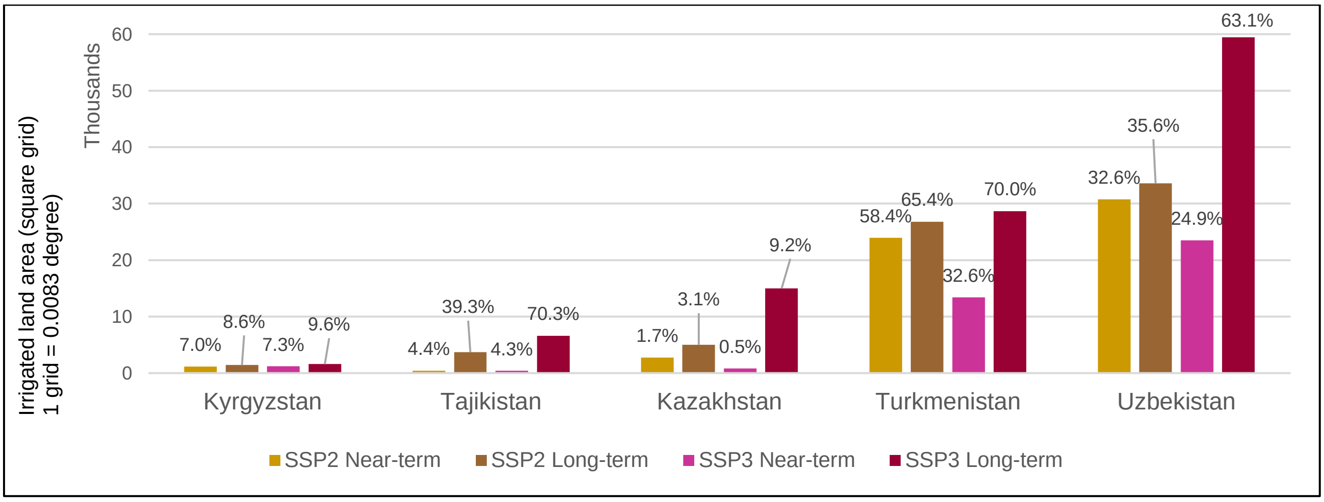
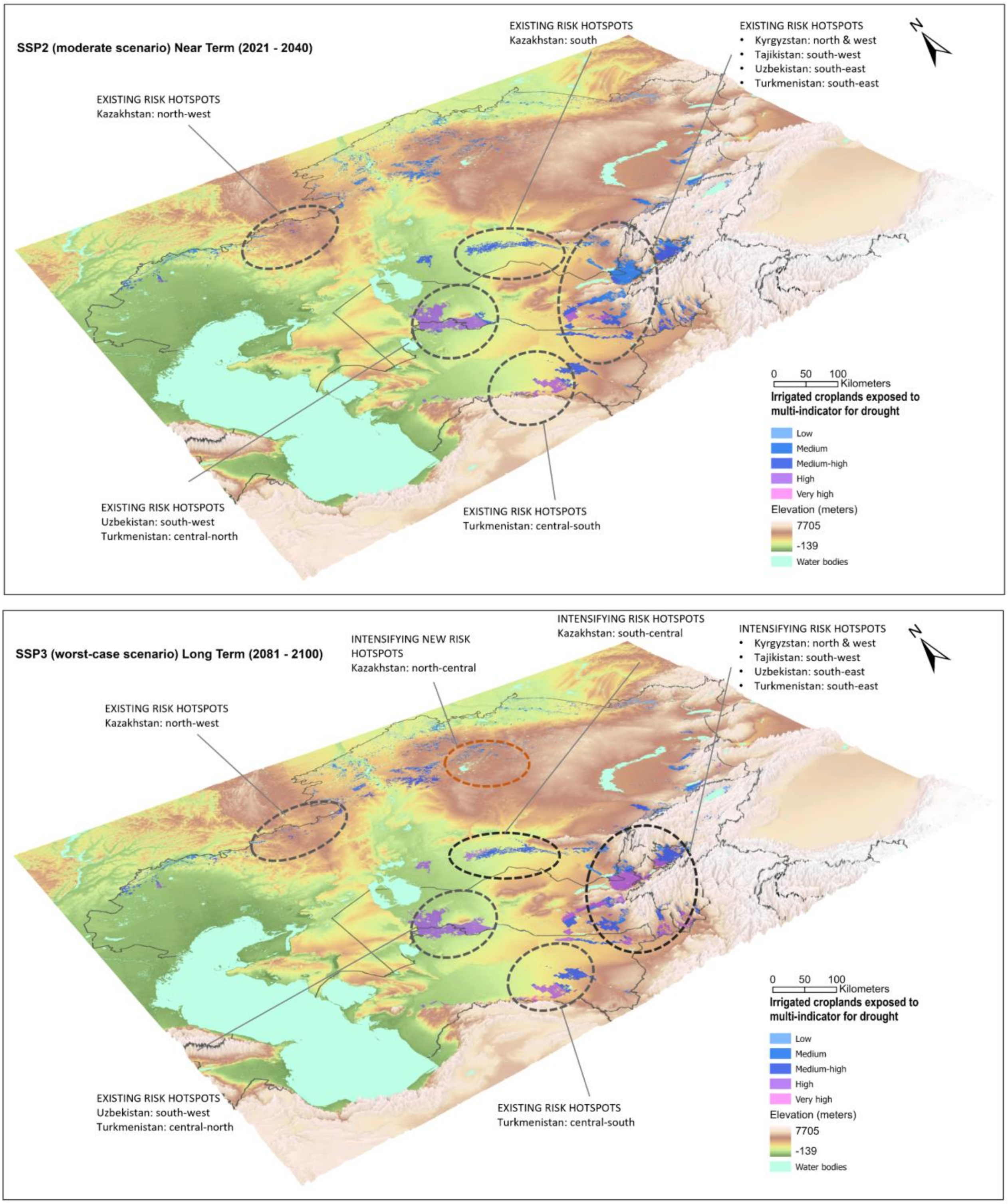


Figure 2-8 – Irrigated agriculture land exposed to multi-indicator for climate under SSP2 (moderate) and SSP3 (worst-case), near term 2021-2040 and long term 2081-2100 scenarios - high to very high risk categories[36]



[36] One square grid in this analytics equals to 1 km^2 at the equator.

Figure 2-9 – 3D visualization of Hotspots of Irrigated agriculture exposure to drought under SSP2 near-term and SSP3 long-term scenarios



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CMIP6) 2021;the Global Aridity Index Version 2, 2019; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003),2018; Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001) 2017; World Water Bodies, 2021; and UN Geospatial.

Notes : 1. The multi-indicator for climate consist of a) Increase in temperature (°C) b) Percent decrease in precipitation, and c) Increase in maximum number of annual consecutive dry days.
2. The Aridity Index for arid and semi-arid regions are all values less than 0.5. The classification is based on generalized climate classification scheme for Aridity Index values (UNEP 1997).
3. Dry day is defined as day with mean precipitation less than 1 mm.

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Irrigated agriculture comprises 18 per cent of the total agriculture in Central Asia.[37] From the total 192 km^2 of irrigated cropland, 18.2 per cent of irrigated land in the region will be exposed to drought categories high to very high risk under SSP2 (moderate) near-term (2021-2040) scenario. The exposure will increase to 21.8 per cent under the SSP2 long-term scenario, and will reach 34.4 per cent under SSP3 (worst-case) long-term (2081-2100) scenario.

Uzbekistan makes up the highest share of total irrigated land in the region and records the highest average irrigated cropland exposure to drought risk across scenarios. The country's irrigated cropland accounts for 68 per cent of the regional total, and 63.1 per cent of this share of irrigated land is exposed to drought under SSP3 long-term scenario. Although Tajikistan accounts for less of the total irrigated land in the region, it still has very high exposure. For example, under the same scenario, Tajikistan shares less than 10 per cent of irrigated land exposure to drought in the region, but the exposed irrigated land area is around 70 per cent of its total irrigated land area (Figure 2-8).

Figure 2-9 depicts 3D visualization of hotspots of irrigated agriculture exposure to drought under SSP2 near-term scenario and SSP3 long-term scenario. The intensifying hotspots under SSP3 long-term scenarios are located in the following areas: a) south-central of Kazakhstan (Jambyl and Kyzylorda Regions); and b) the neighboring areas of north (Chui and Naryn Regions) and west of Kyrgyzstan (Batken and Osh Regions), south-west Tajikistan (Khatlon Region), and central-north (Dasoguz Region) and south-east parts of Turkmenistan (Lebap and Mary Regions); and central of Uzbekistan (Navoi Region).

Hotspots that are about the same intensity as in SSP2 near-term are in a) north-west of Kazakhstan (West Kazakhstan Region); and b) south-west parts of Uzbekistan (Republic of Karakalpakstan and Fergana Region) and central-north of Turkmenistan (Dasoguz Region), and 5) central-south of Turkmenistan (Ahal Region).

The emerging and intensifying hotspots will occur in the North-central of Kazakhstan (Akmola and Kostanay Regions).

2.2 Hotspots on agriculture land exposure to multi-criteria indicators related to flood

In addition to drought, Central Asia is also exposed to flood. Flash floods are usually triggered by heavy rainfall events and/or glacial lake outburst floods and occur in steeply sloping valleys in mountainous areas where loose sediment, gravel, and other debris are available to be mobilised. Further, most mountainous areas have a high density of steep alpine streams, which deliver runoff and sediment rapidly to the valleys below. **As a result of the rising intensity of rainfall events, flash floods and mudflows have become increasingly problematic in Central Asia**.[38]

The multi-criteria indicators in agriculture exposure to flood analytics consist of: 1) projected rainfall intensity, 2) slope, 3) flow accumulation, 4) elevation and 5) geology/soil type. After being processed and scored, these are overlaid with the agriculture land area (rainfed and irrigated). The following analysis shows exposure of rainfed and irrigated agriculture to these multi-criteria indicators for flood.

Hotspots of rainfed agriculture land exposure to flood

The rainfed agricultural land classified as hotspots with a medium-high to very high risk of flash flooding under SSP3 long-term (2081 – 2100) scenario, are located in eastern and south-eastern Kazakhstan, north and central Kyrgyzstan, south-western Tajikistan, south-eastern Uzbekistan, and south-eastern

[37] ESCAP calculations based on NASA GFSAD data.
[38] Thurman M., (2011). Natural Disaster Risks in Central Asia: A Synthesis. Available at: https://www.preventionweb.net/publication/natural-disaster-risks-central-asia-synthesis.

Turkmenistan as illustrated in Figure 2-10 and and Figure 2-14 b.

Under the SSP3 long-term scenario, Kazakhstan will have the highest exposure of rainfed agricultural land area to flood risk, followed by Kyrgyzstan. The amount of rainfed cropland exposure in Kazakhstan is 18.6 per cent of total rainfed land in the country. Although the rainfed cropland exposure to drought in Kyrgyzstan is half of Kazakhstan, but it is around 94.1 per cent of its total rainfed land in that country (Figure 2-11).

Figure 2-10 – Hotspots of Rainfed agriculture exposure to flood under SSP3 (worst-case scenario) 2081-2100

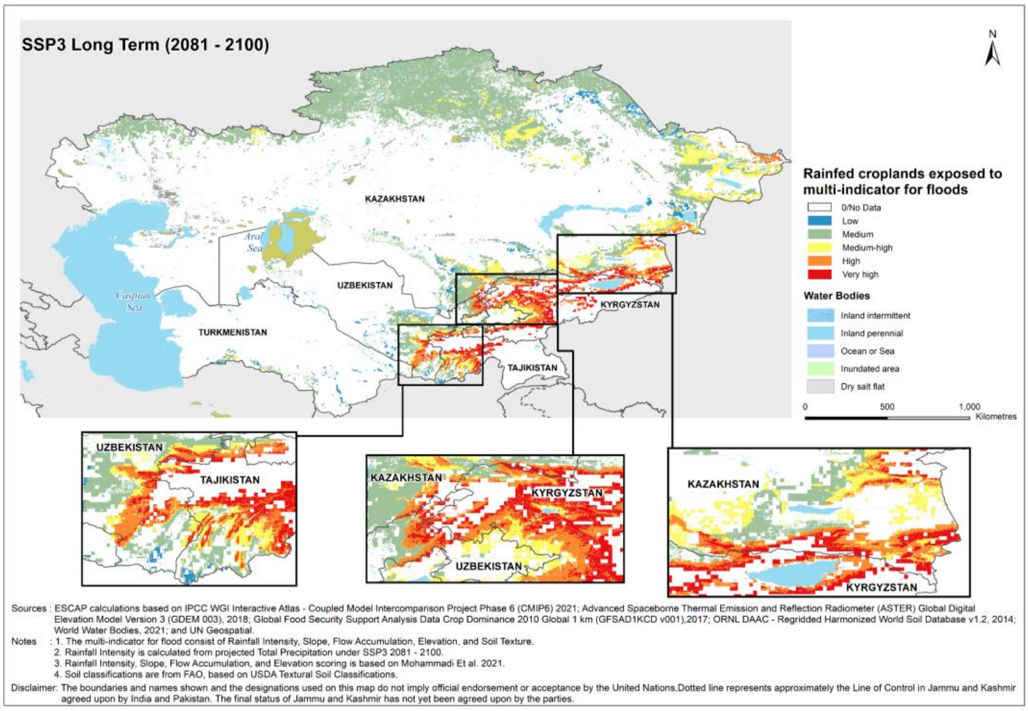
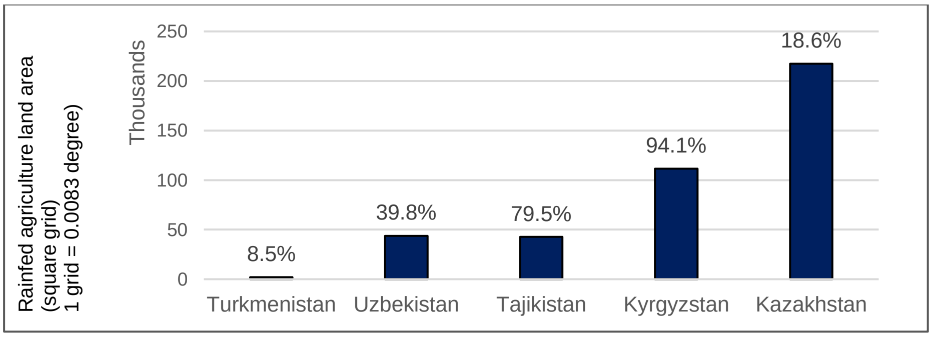


Figure 2-11 – Rainfed agriculture land exposed to multi-indicator for flood under SSP3 (worst-case) long term 2081-2100 scenarios - medium-high to very high risk categories



Hotspots of irrigated agriculture land exposure to flood

The irrigated cropland in the region is also exposed to flood risk. Figure 2-12 shows the irrigated agricultural land exposed to multi-indicator for flood risk under SSP3 long term (2081 – 2100).

Figure 2-12 – Irrigated agriculture land exposed to multi-indicator for flood under SSP3 (worst-case) long term 2081-2100 scenarios - medium-high to very high risk categories

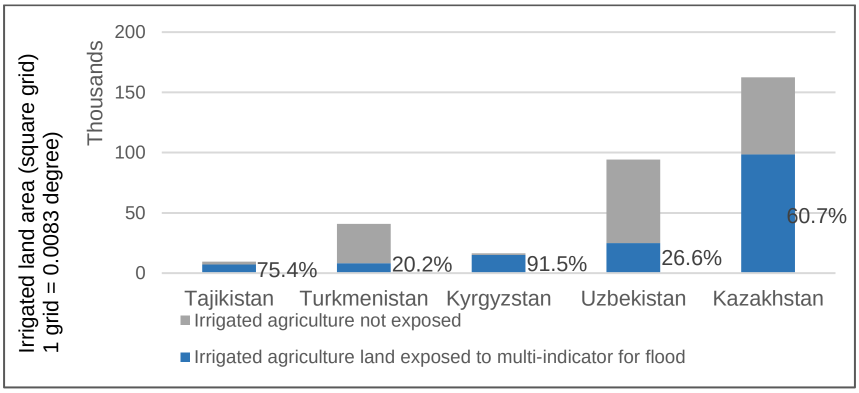
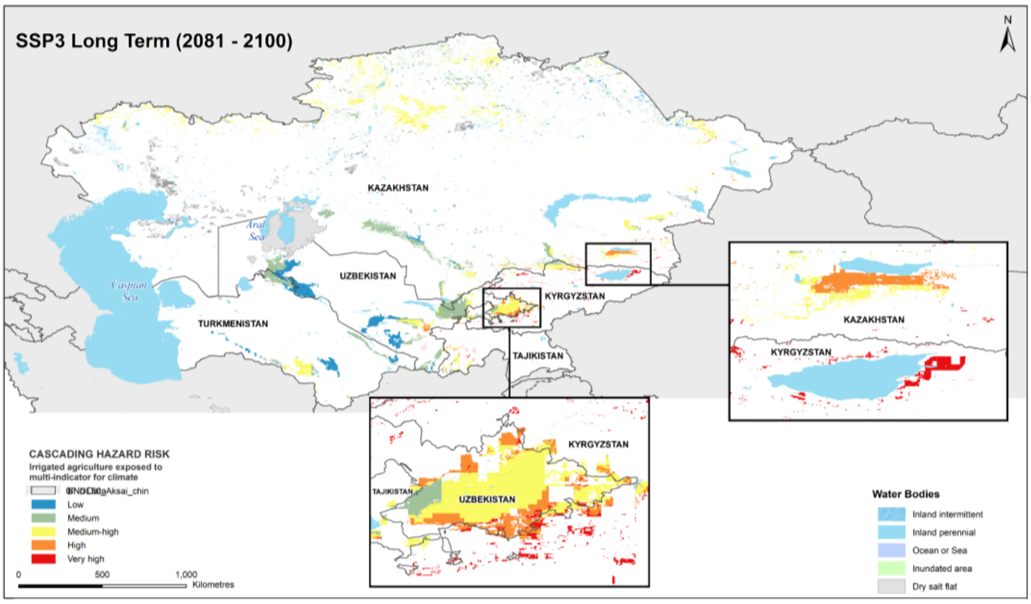


Figure 2-13 – Irrigated agriculture land exposed to multi-indicator for flood under SSP3 (worst-case scenario) 2081-2100



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CMIP6) 2021; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003), 2018; Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001), 2017; ORNL DAAC - Regridded Harmonized World Soil Database v1.2, 2014; World Water Bodies, 2021; and UN Geospatial.

Notes : 1. The multi-indicator for flood consist of Rainfall Intensity, Slope, Flow Accumulation, Elevation, and Soil Texture.
2. Rainfall Intensity is calculated from projected Total Precipitation under SSP3 2081 - 2100.
3. Rainfall Intensity, Slope, Flow Accumulation, and Elevation scoring is based on Mohammadi Et al. 2021.
4. Soil classifications are from FAO, based on USDA Textural Soil Classifications.

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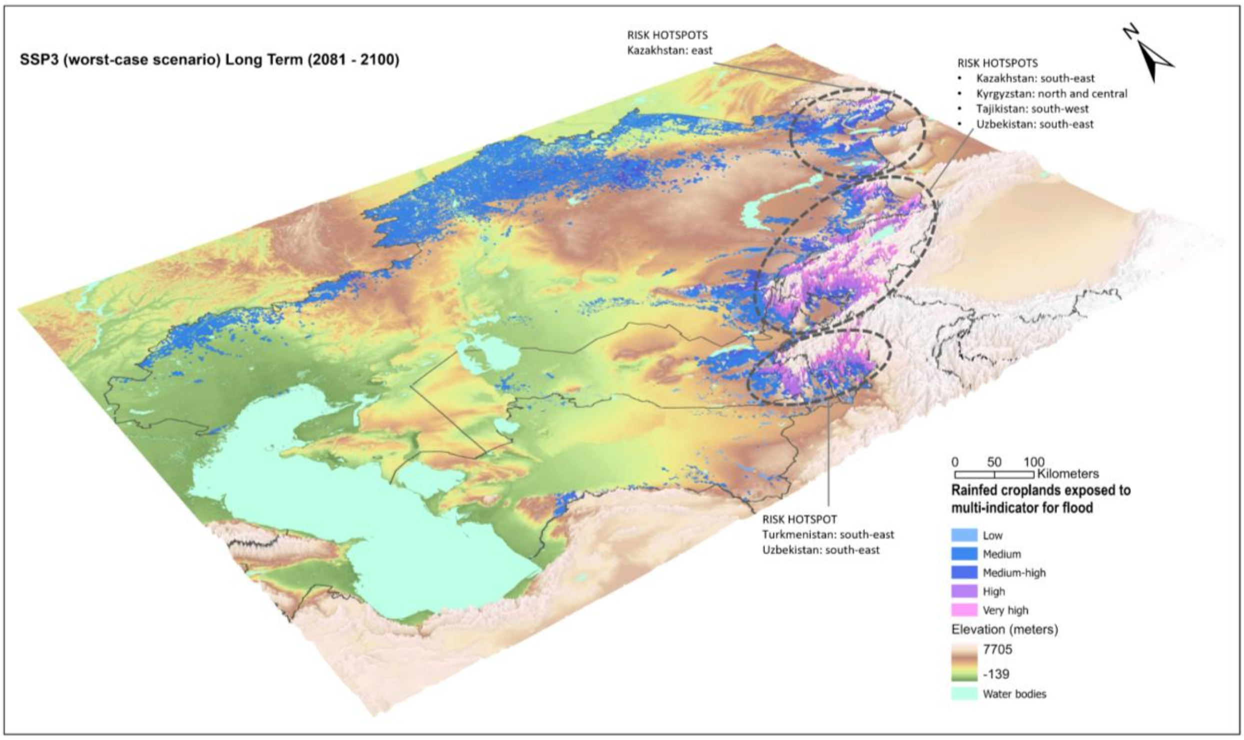
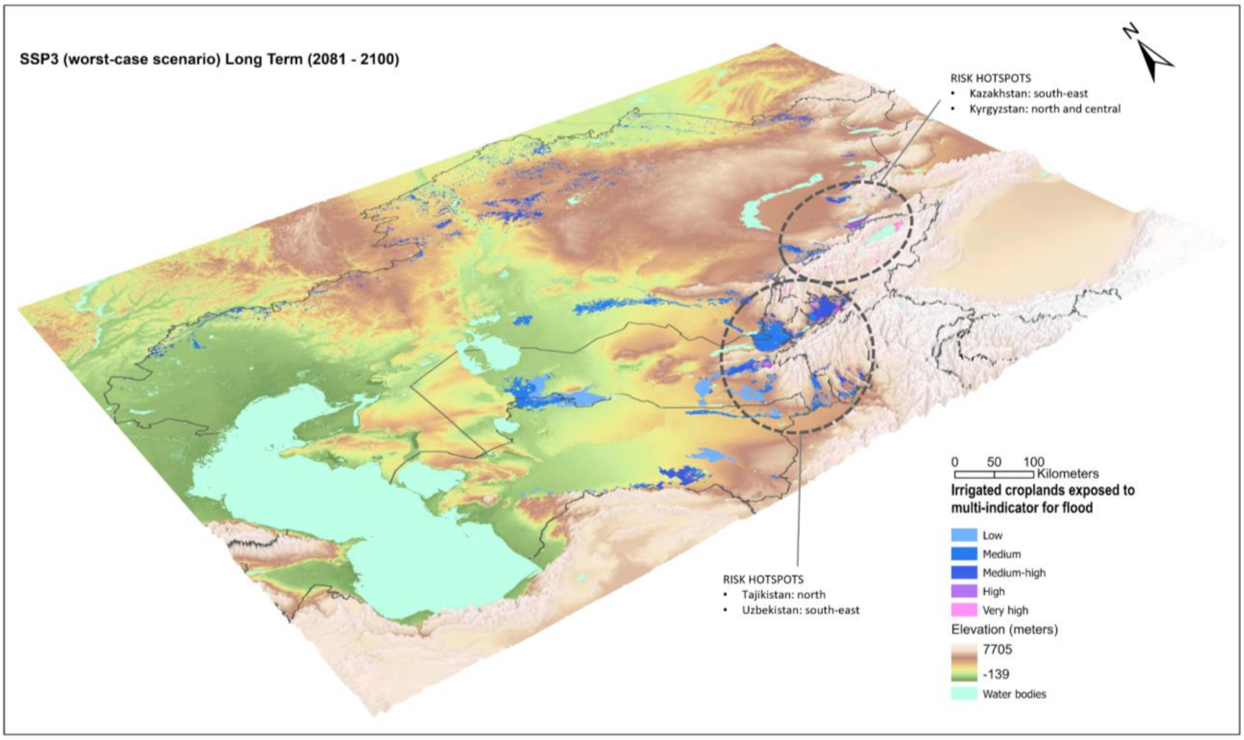
In terms of hotspots for the exposure, south-eastern parts of Uzbekistan like Fergana and Andizhan Regions and northern and central parts of Kyrgzstan like Batken, Osh and Issyk-Kul Regions are exposed to medium high to very high category of flood risk, as depicted in Figure 2-13 and Figure 2-14 b.

Figure 2-14 – 3D visualization of Hotspots of Rainfed and Irrigated agriculture exposure to flood under SSP3 long-term scenarios





Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CMIP6) 2021; ORNL DAAC - Regridded Harmonized World Soil Database v1.2, 2014; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003),2018; Global Food Security Support Analysis Data Crop Dominance 2010 Global 1 km (GFSAD1KCD v001) 2017; World Water Bodies, 2021; and UN Geospatial.

Notes : 1. The multi-indicator for flood consist of Rainfall Intensity, Slope, Flow Accumulation, Elevation, and Soil Texture.
2. Rainfall Intensity is calculated from projected Total Precipitation under SSP3 2081-2100.
3. Rainfall Intensity, Slope, Flow Accumulation, and Elevation scoring is based on Mohammadi Et al. 2021.
4. Soil classifications are from FAO, based on USDA Textural Soil Classifications.

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2.3 Summary of the agricultural exposure hotspots

Central Asia has various types of agriculture exposure to hazards. Figure 2-15 compares the total cropland exposure to drought and flood, illustrating that drought accounts for a higher share of the rainfed agriculture exposure. Under the worst-case (SSP3) long-term scenarios, approximately 42.8 per cent of rainfed agriculture area will be exposed to drought, this exposure is 1.8 times the rainfed agriculture exposed to flood. In addition, while 42.8 per cent of the total rainfed agriculture land area is exposed to multi-indicator for drought, 23.2 per cent is exposed to multi-indicator for flood. **Overall, under the worst-case long term scenario, drought exposure in both types of agricultural lands is higher than flood exposure.**

Figure 2-15 – Total Irrigated and Rainfed agriculture land exposure to multi-indicator for flood and drought under SSP3 (worst-case) long term 2081-2100 scenarios - medium-high to very high risk categories

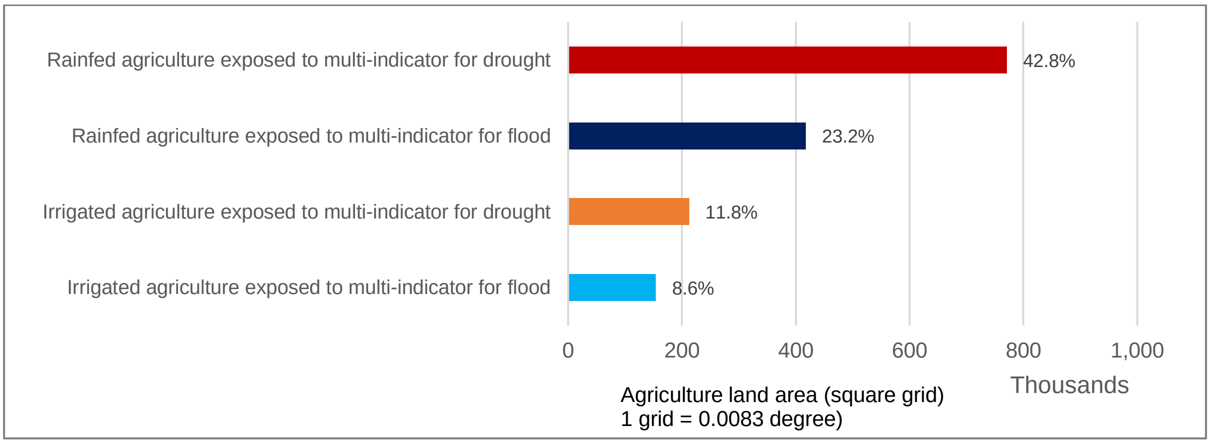
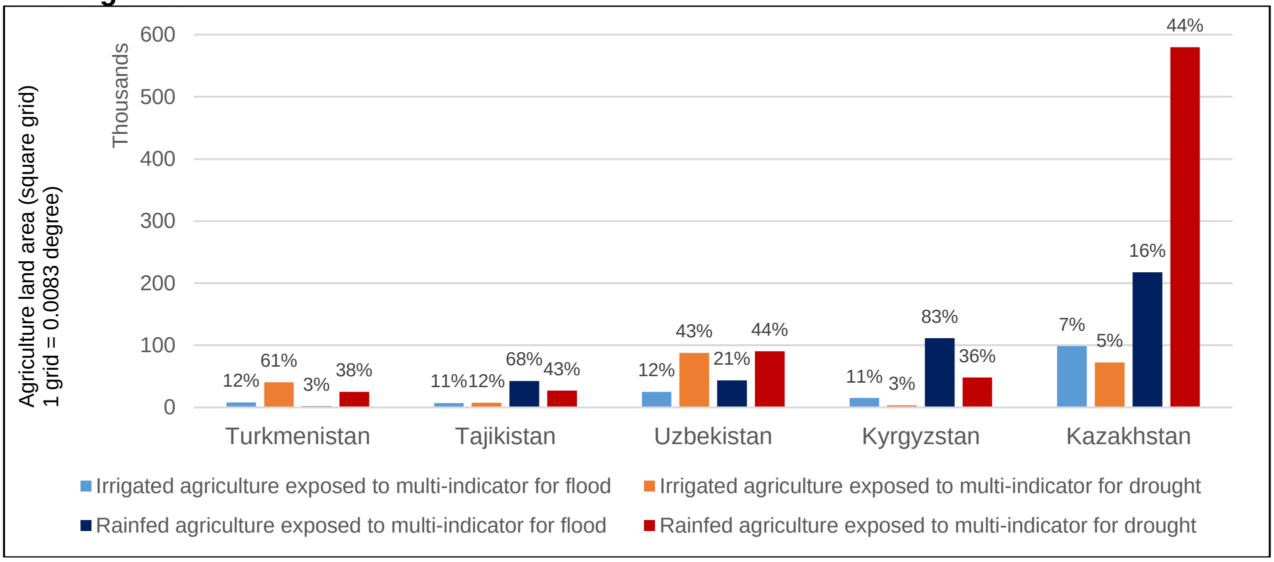


Figure 2-16 – Irrigated and rainfed agriculture land exposed to multi-indicator for flood and drought under SSP3 (worst-case) long term 2081-2100 scenarios - medium-high to very high risk categories



Note: Per cent exposure are as of total agriculture land in each country.

Table 2-1 – Subnational hotspots of Irrigated and Rainfed Agriculture in arid areas exposed to multi-indicator for drought and flood under worst-case climate scenario (SSP3), long-term

Country	Rainfed agriculture land exposed to drought	Rainfed agriculture land exposed to flood	Irrigated agriculture land exposed to drought	Irrigated agriculture land exposed to flood
Kazakhstan	north-west (**Andizhan**, **Fergana**, **Namangan**)		north-west (**West-Kazakhstan**)	
	north-central (**Akmola, Kostanay**)	north-central (**Akmola, Karagandy**)	north-central (**Kostanay**)	north-central (**Akmola, Kostanay**)
	north-east (**East-Kazakhstan, Pavlodar**)	north-east (**East-Kazakhstan**)		
	south-east (**Almaty**)	south-east (**Almaty**)		south-east (**Almaty**)
	south-central (**Jambyl**)	south-central (**Jambyl**)	south-central (**Jambyl, Kyzylorda**)	
Kyrgyzstan	north and central (**Naryn**)	north and central (**Naryn**)	north and central (**Naryn**)	north and central (**Chui**)
	west (**Jalal-Abad, Osh**)	west (**Jalal-Abad, Osh**)	west (**Batken, Osh**)	
Tajikistan	north-west (**Sughd Region**)		north-west (**Sughd Region**)	
	south-west (**Khatlon Region**)	south-west (**District of Republican Subordination, Khatlon Region**)	south-west (**Khatlon Region**)	south-west (**Khatlon Region**)
Turkmenistan			north-central (**Dasoguz Region)**	
	south-central (**Ahal Region**)	south-central (**Ahal Region**)	south-central (**Ahal Region**)	south-central (**Ahal Region**)
		south-east (**Lebap Region**)		
Uzbekistan	central (**Navoi**)		central (**Navoi**)	
		north-east (**Tashkent**)		
	south-east (**Dzizhak**, **Kashkadarya**, **Surkhandarya**)	south-east (**Dzizhak**, **Kashkadarya**, **Surkhandarya**)		south-east (**Samarkand**)
			south-west (**Republic of Karakalpakstan**)	
				east (**Andizhan**, **Fergana**, **Namangan**)

Across Central Asia, Kazakhstan records the highest rainfed agriculture exposure to drought, covering 44 per cent of the country's cropland area, while the highest rainfed agriculture exposure to flash floods is recorded in Kyrgyzstan, covering 83 per cent of the country's total cropland (Figure 2-16). Uzbekistan is at high risk, with 43 per cent of its irrigated agriculture land and 44 per cent of its rainfed agriculture exposed to drought. In Tajikistan, flood risk on rainfed agriculture is the highest, around 68 per cent of the total cropland. Whereas in Turkmenistan drought accounts for the highest portion of the irrigated agriculture exposure, with nearly 60 per cent of the total cropland in the country exposed to drought.

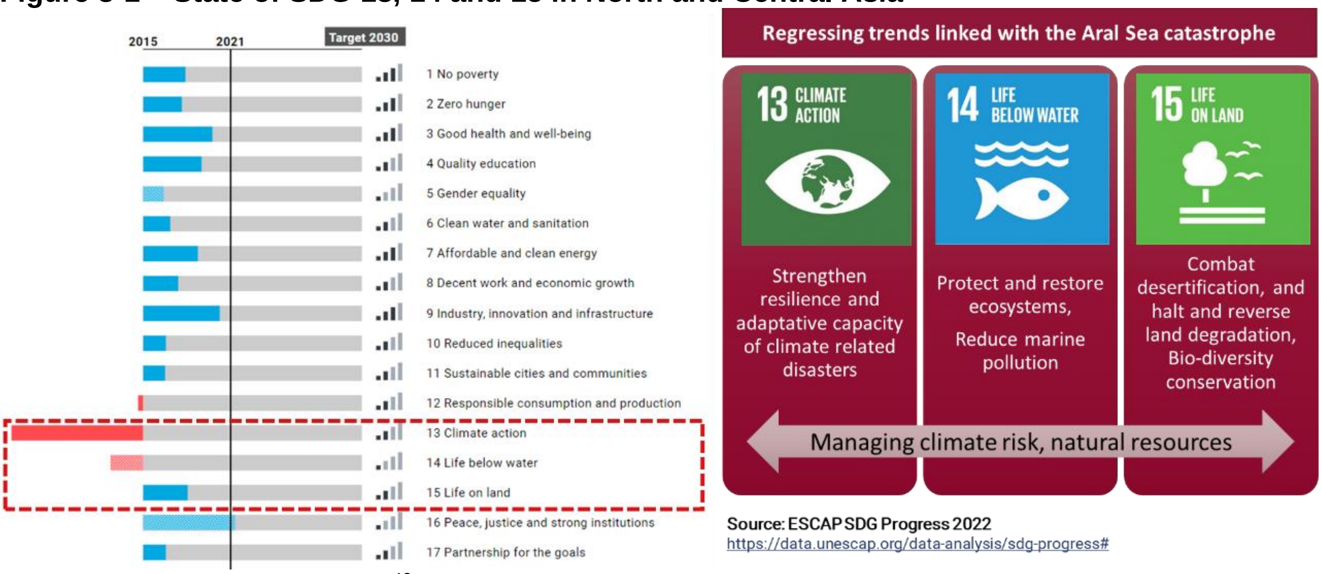
While figure 2-16 shows the highest exposure across countries, Table 2-1 presents the subnational hotspots of irrigated and rainfed agriculture in arid areas exposed to multi-indicator for drought and flood under SSP3 (worst-case) long term climate scenario. When studied together, they bring forth the varying scale of sub-national hotspots. For instance, the sub-national hotspots of rainfed agriculture land exposed to drought (red bars, Figure 2-16) in Kazakhstan are vaster than those in Uzbekistan. Therefore, these hotspots in Kazakhstan (namely Andizhan, Fergana, Namangan in the north-west, Akmola, Kostanay in north-central, East-Kazakhstan, Pavlodar in north-east, Almaty in south-east and Jambyl in south-central) take up a bigger share of land area than those in Uzbekistan (namely Navoi in the central and Dzizhak, Kashkadarya, Surkhandarya in the south-east).

3. Adaptation and resilience pathways

3.1 SDG progress and resilience of North and Central Asia

Significant progress has been made towards achieving several SDGs in North and Central Asia (Figure 3-1). Nevertheless, gaps remain, especially as regression is recorded for several goals such as Goal 13 on climate action and Goal 14 on life below water. Progress in climate action is needed to achieve Target 13.1 on resilience and adaptive capacity and Target 13.2 on climate change policies.[39] In Central Asia, progress in achieving targets of Goal 15 on life on land should be accelerated, particularly to achieve Target 15.1 on terrestrial and freshwater ecosystems, Target 15.2 on sustainable forest management, Target 15.4 on conservation on mountain ecosystems, Target 15.5 on loss of biodiversity and Target 15.8 on invasive alien species. These are significantly related to the Aral Sea Catastrophe.

Figure 3-1 – State of SDG 13, 14 and 15 in North and Central Asia



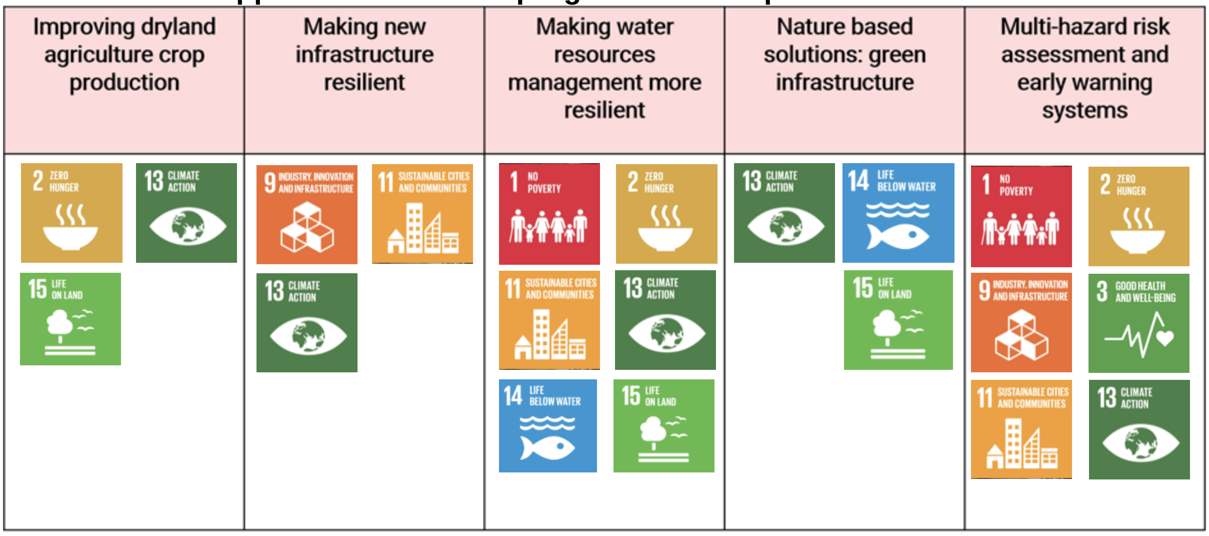
Source: ESCAP SDG Progress 2022[40]

3.2 Restoration of Aral Sea holds the key for achieving SDGs in Central Asia

In order to achieve the Sustainable Development Goals (SDGs), the study suggests five key adaptation strategies for the transboundary hazard of the Aral Sea disaster: 1) Improving dryland agriculture crop production; 2) Making new infrastructure resilient; 3) Making water resources management more resilient; 4) Nature-based solutions: green infrastructure and 5) Strengthening multi-hazard risk assessment and early warning systems (Figure 3-2). Conceptually, this is based on The Global Commission on Adaptation for resilience[41].

[39] United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), (2022). Asia and the Pacific SDG Progress Report 2022. Available at: https://www.unescap.org/kp/2022/asia-and-pacific-sdg-progress-report-2022.
[40] United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), (2022). ESCAP Asia-Pacific SDG Gateway – SDG Progress. Available at: https://data.unescap.org/data-analysis/sdg-progress#. Accessed on 28 March 2022.
[41] Global Center on Adaptation, (2019). Adapt now: a global call for leadership on climate resilience. Available at: https://gca.org/reports/adapt-now-a-global-call-for-leadership-on-climate-resilience/.

Figure 3-2 – Adaptation priorities for managing and mitigating in-land water disasters in the Aral Sea that also support simultaneous progress on multiple SDGs



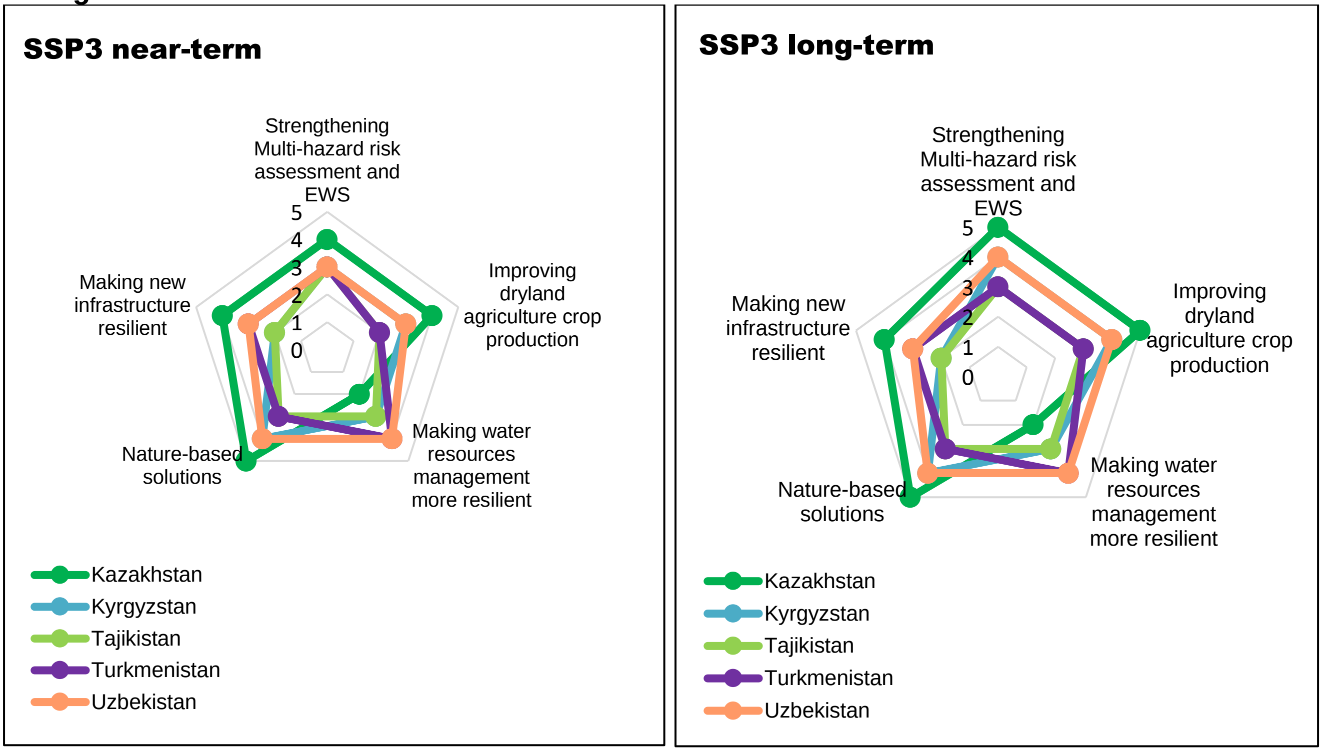
3.3 Building a more resilient Central Asia through key adaptation measures

A Decision Support System (DSS) tool is under the development for the transboundary hazard in the Aral Sea, as part of the Risk and Resilience Portal[42]. This DSS tool is aimed at supporting countries in understanding their disaster and climate riskscape and building resilience. The transboundary nature of disaster requires transboundary cooperation. This can potentially help reverse the current SDG trends on Goal 13 and Goal 14. Thus, countries need to invest in key adaptation priorities specific to their disaster riskscape.

Proxy indicators mentioned in the second column of Table 3–1 were used to develop adaptation priorities scores for each country in Central Asia based on categories of Strengthening Multi-hazard risk assessment and Early-warning systems; Improving dryland agriculture crop production; Making water resources management more resilient; Nature-based solutions; and Making new infrastructure resilient. Figure 3-3 provides the adaptation matrices for the Aral sea for the worst-case climate scenari

[42] ESCAP Risk and Resilience Portal. Available at: https://rrp.unescap.org/. Accessed in March 2022.

Figure 3-3 – Climate adaptation priorities matrix for Central Asia, under worst-case climate change scenarios



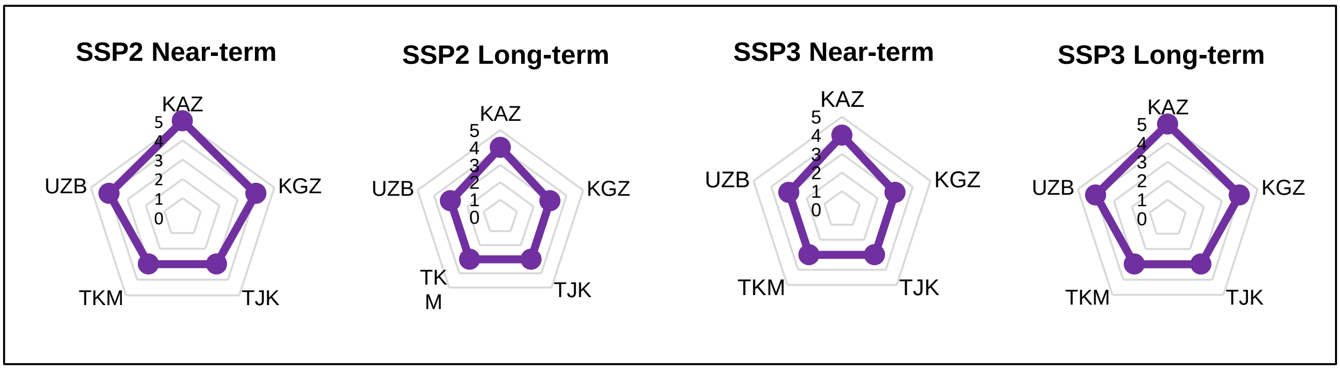
Strengthen Multi-hazard risk assessment and Early-warning systems

In Central Asia, multi-hazard risk assessment and early warning systems are highly useful in mitigating all types of cropland exposure to multi-hazard, particularly drought, and flood. Early warning monitoring is necessary to plan and reduce the impact of multi-hazard on agriculture, which is directly linked to food security, and the impact of multi-hazard on people. Adaptation priorities to Strengthen Multi-hazard risk assessment and Early warning systems, and Improving dryland agriculture crop production have the greatest scores for all 5 countries for different climate change scenarios, consistent with shared socioeconomic pathways (SSPs). As illustrated in Figure 3-4 a and Figure 3-4 b, Kazakhstan has the greatest score for both adaptation priorities across all the climate change scenarios. The score for Adaptation priority to Strengthen Multi-hazard risk assessment and Early-warning systems is based on the relative area of cropland exposed to drought and flood risks under different climate change scenarios.

Table 3–1 Proxy indicators for constructing adaptation matrix

Adaptation priorities	Proxy indicators
Strengthening Multi-hazard risk assessment and Early-warning systems	• Rainfed and Irrigated agriculture exposure to multi-hazard
Improving dryland agriculture crop production	• Rainfed agriculture exposure to multi-hazard.
Making water resources management more resilient	• Percent areas that contribute to the Aral Sea. • Dependency on irrigation.
Nature-based solutions: green infrastructure	• Forest, shrub, and grassland cover
Making new infrastructure resilient	• Infrastructure spending and GDP.

Figure 3-4 a – The relative score for adaptation priority in Strengthening Multi-hazard risk assessment and Early-warning systems across social shared pathways scenarios

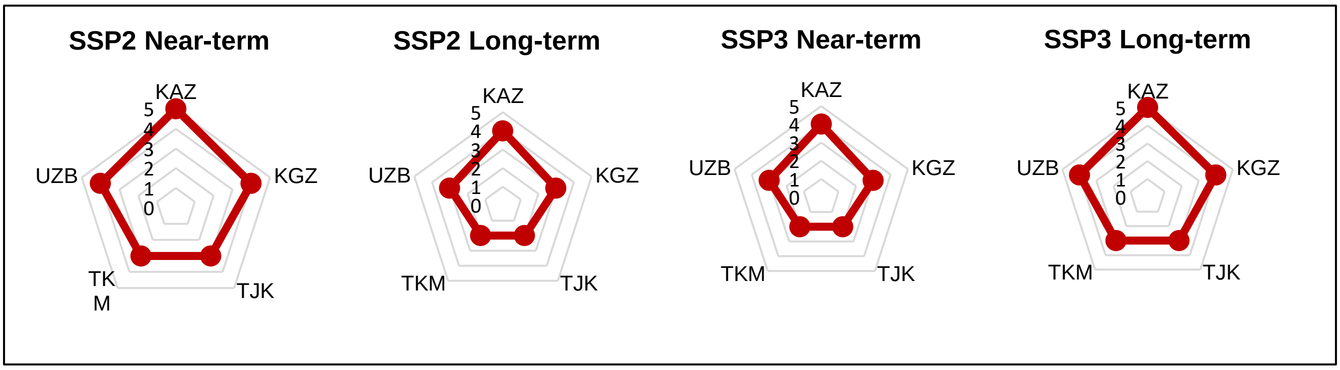


Improving dryland agriculture crop production

Agriculture in Central Asia is dominated by dryland agriculture, in which rainfed land covers 82 per cent of the total cropland. These rainfed croplands are highly dependent on precipitation but are susceptible to hydrometeorological multi-hazard such as drought and flood, possibly impeding on the levels of precipitation.

The score for Adaptation priority for improving dryland agriculture is based on the relative area of Rainfed croplands dependent on irrigation and exposed to multi-hazard risk of drought and flood under different climate change scenarios. As indicated in Figure 3-4 b, Kazakhstan has the highest score, followed by Kyrgyzstan, Uzbekistan, Tajikistan and lastly,Turkmenistan.

Figure 3-4 b – The relative score for adaptation priority of Improving dryland agriculture crop production

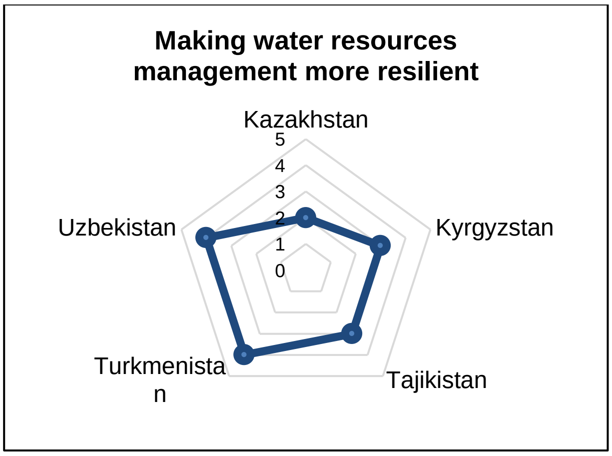


Making water resources management more resilient

The calculation of this priority for Aral Sea countries is based on the proportion of their land that is part of the Aral Sea while depending on irrigation. The areas of irrigated land in each country, as mentioned in section 2-1 are used to calculate the dependency to irrigation. Tajikistan, Turkmenistan and Uzbekistan have the highest per cent of areas which contribute to the Aral Sea. Whereas, Turkmenistan has the highest dependency on irrigation, followed by Uzbekistan.

Making water resources management more resilient (Figure 3-4 c) is of highest priority in Uzbekistan and Turkmenistan with a score of 4, followed by Kyrgyzstan, and Tajikistan with a score of 3 and Kazakhstan with 2.

Figure 3-4c – The relative score for Making water resources management more resilient as adaptation priority

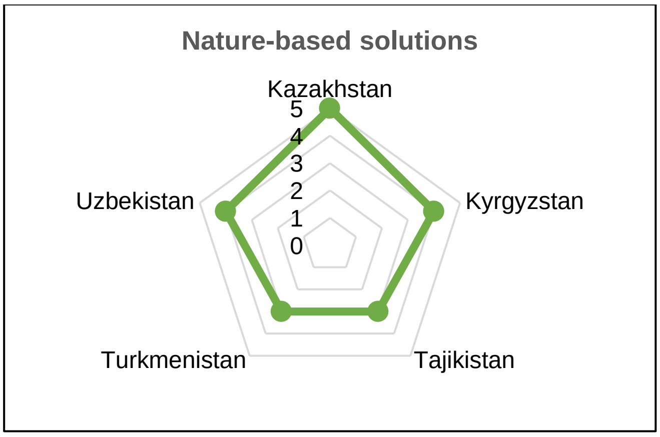


Nature-based solutions: green infrastructure

Forests can soak up excess rainwater, preventing run-offs and damage from flooding. By releasing water in the dry season, forests can help to provide clean water and mitigate the effects of droughts. We can create better policies to tackle the effects of climate change and extreme weather events by better understanding the role of forests in retaining water.[43] Central Asia's total forest, shrub, and grassland cover are 2.1 million km^2, or 52.7 percent of the total land area (Figure 3-4 e). It is 2.6 times the total area of agricultural land. Kazakhstan covers 81.3 per cent of the total forest, shrub, and glass land cover, followed by Kyrgyzstan at 5.7 per cent, Uzbekistan at 4.9 per cent, Turkmenistan at 4.5 per cent and Tajikistan at 3.6 per cent.

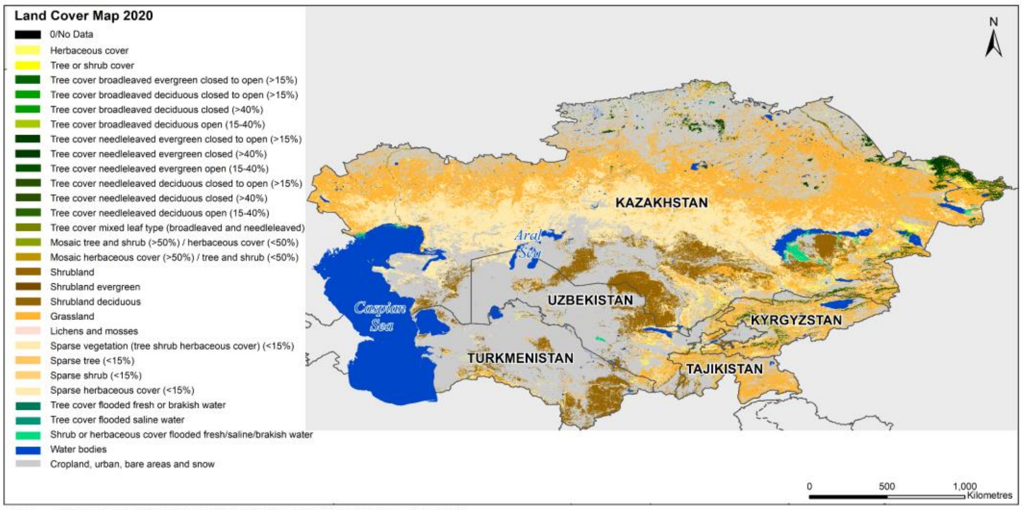
The adaptation priority for Nature-based solutions (Figure 3-4 d) has the highest score of 5 for Kazakhstan, followed by Uzbekistan and Kyrgyzstan with 4, and Turkmenistan and Tajikistan with 2. The score for Nature-based solutions adaptation priority is based on the relative area of land under category of "forest, shrub and grass" land cover (Figure 3-4 e).

Figure 3-4 d – The relative score for adaptation priority for Nature-based solutions

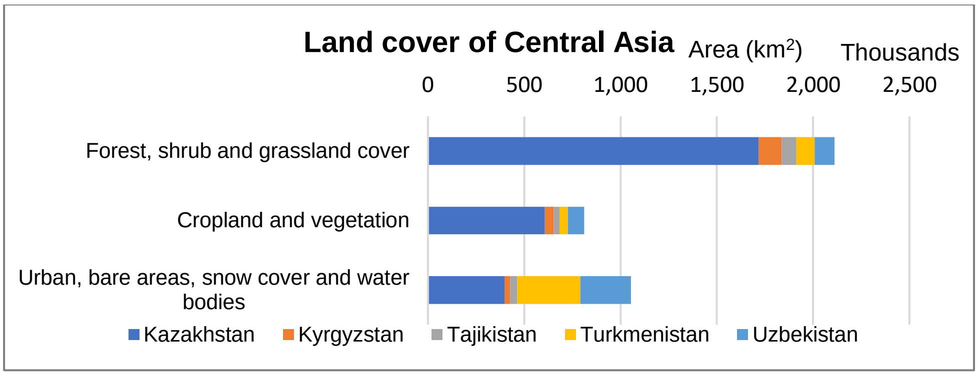


[43] European Environmental Agency (EEA), (2015). Water-retention potential of Europe's forests - A European overview to support natural water-retention measures. Available at: https://www.eea.europa.eu/publications/water-retention-potential-of-forests.

Figure 3-4 e – Land cover classification of Central Asia



Source : ESCAP based on Climate Change Initiative (CCI) Global Land Cover, 2020; and UN Geospatial.
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

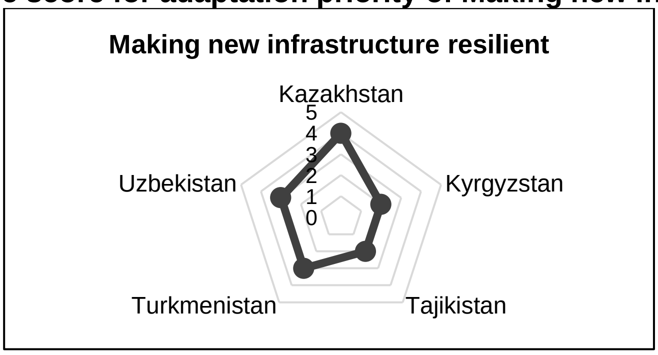


Making new infrastructure resilient

Infrastructure spending in Central Asia is estimated at nearly 2.2% of GDP.[44] Infrastructure spending in Central Asia is based on the World Bank Refinement 4 method by using state-owned enterprises (SOE-augmented BOOST World Bank Database and fitted values). With the assumption of 1:5 resilience cost: that is every $5 spent in infrastructure, $1 should be allocated for resilience.

The adaptation priority for making new infrastructure resilient (Figure 3-4 f) has the highest score of 4 for Kazakhstan, followed by Uzbekistan and Turkmenistan at 3, and Kyrgyzstan and Tajikistan at 2.

Figure 3-4 f –The relative score for adaptation priority of Making new infrastructure resilient



[44] World Bank Group, (2019). Policy Research Working Paper 8730. Hitting the Trillion Mark - A look at how much countries are spending on Infrastructure. Available at: https://documents1.worldbank.org/curated/en/970571549037261080/pdf/WPS8730.pdf.

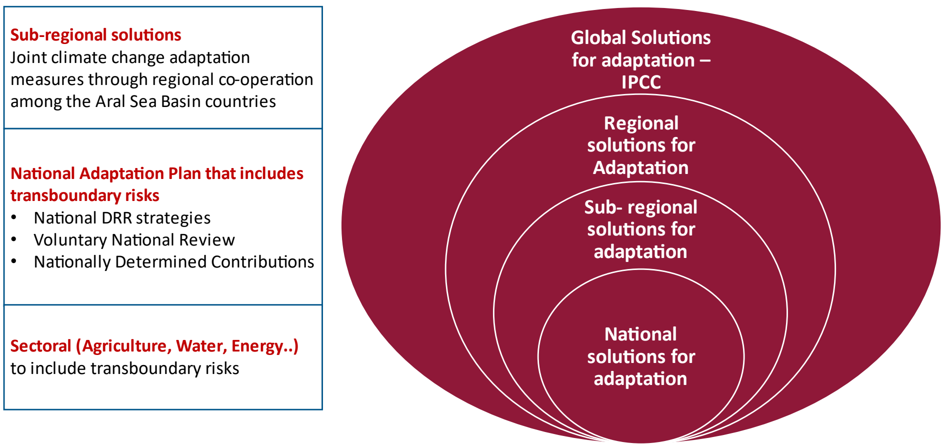
The Annualized Average Loss (AAL) for climate related hazards in Central Asia under the worst-case climate scenario[45] is $8 billion while the adaptation costs is $1.6 billion. Countries of Central Asia can get close to US$5 return for every dollar invested in adapting to climate hazards. The economic losses caused by climate-related hazards are quite significant and to the extent of 9.0 percent of GDP per year in the region. Therefore, capitalizing on Central Asia Hydrometeorology Modernization Project along with the World Bank, Executive Committee of International Fund for Saving the Aral Sea (EC IFAS), and the national hydrometeorological services are a positive way forward to build resilience.

3.4 Next Step: Towards a sub-regional cooperation mechanism - Transboundary cooperation in the Aral Sea

Overall, as highlighted in this report, the key indicators of climate change in Central Asia are drought and growing desertification in the region, as well as state of glaciers and snow cover, and flood risk. Floods are set to be more severe and prolonged while droughts will become more frequent and lengthier. In this context, adaptation measures discussed above must also integrate climate change scenarios into various long-term plans, programs at all administrative levels, regional, sub-regional, national and sub-national.

In transboundary hazards, teleconnections exist between natural resources and natural ecosystem services. While economic and social linkages do alter the nature of teleconnection, climate change impacts are quite substantial in altering this relationship. The present study on the Aral Sea catastrophe considers this relationship and quantifies risk and its impacts in time domain from 2020 to 2100. The study anchors sub-regional adaptation and resilience pathways that capture the teleconnection between natural resources and natural ecosystem services in the changing climate risk scenarios of the Aral Sea. Further, the transboundary nature of the natural hazards and potential disruptions in ecosystem services in the Aral Sea basin must inform sub-regional cooperation on adaptation, national adaptation measures and disaster risk reduction plans as well as sectoral development work with line ministries like agriculture/food, water and energy (Figure 3-5).

Figure 3-5 Taxonomy of solutions for climate change adaptation and DRR Sub-regional context of a transboundary hazard – the Aral Sea that represents shared vulnerabilities and risks



[45] The worst-case climate scenario in Average Annual Loss quantification is based on Coupled Model Intercomparison Project 5 (CMIP5) data, RCP 8.5 near-term and mid-term.

Moving forward, the following areas of collaborative work can become the three pillars of adaptation acceleration for protecting the Aral Sea basin.

The first pillar focusses on knowledge sharing and capacity development of all countries in multi-hazard risk assessment and early warning systems, nature-based solutions, dryland agriculture and water resilient infrastructure.

The second can take form of a toolkit for risk-informed decision making. For example, the ESCAP Risk and Resilience portal offers decision support system (DSS) tools for managing transboundary hazards.

Three, sub-regional partnership platform on managing in-land water disasters in the Aral Sea can be taken forward at forums like the North and Central Asian Multi-Stakeholder Forum on Implementation of Sustainable Development Goals[46]. The fifth session of this forum in October 2021 discussed the implementation of SDGs 14 and 15 in face of the challenges of biodiversity and ecosystems restoration in a changing climate and recommended subregional cooperation mechanisms for addressing transboundary challenges. Government of Kyrgyzstan's tabling of the resolution A/75/271 entitled "Nature knows no borders: transboundary cooperation – a key factor for biodiversity conservation, restoration and sustainable use" at the 75th session of the United Nations General Assembly would help achieve co-benefits for climate change adaptation and mitigation.

Figure 3-6 – Managing in-land water disasters in the Aral Sea

The Committee on Disaster Risk Reduction of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) at its 7th session held on 25-27 August 2021 recommended a scale-up of regional and subregional cooperation strategies on disaster risk reduction and climate resilience to complement national efforts in implementing the 2030 Agenda for Sustainable Development. It's in the above context that ESCAP conducted two parts of analytical studies:

> Part I: Aral Sea, Central Asian Countries and Climate Change in the 21st Century; and
> Part II: Managing in-land water disasters in the Aral Sea: sub-regional pathways for adaptation and resilience

These studies focus on developing regional

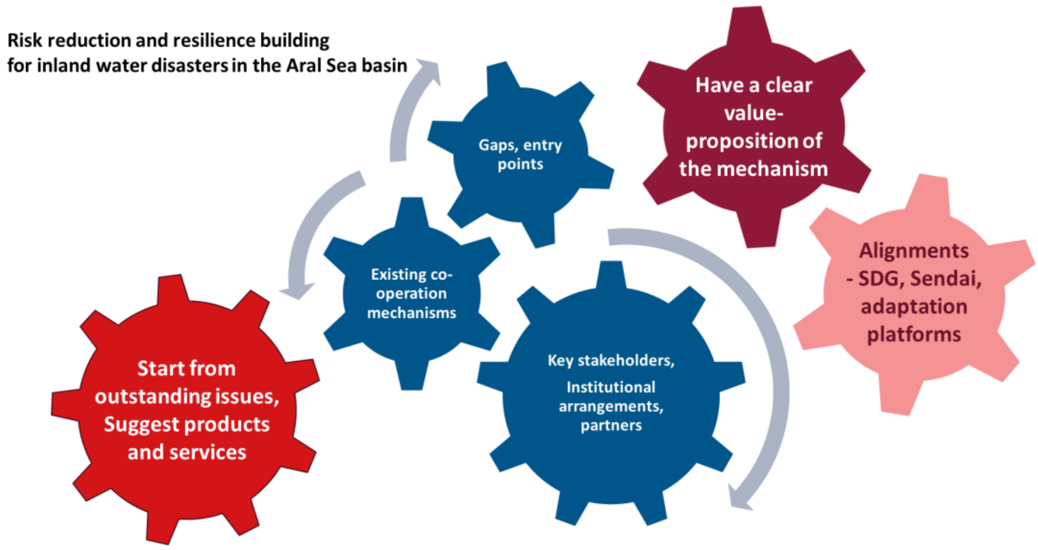
[46] United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), (2022). Fifth North and Central Asian Multi-stakeholder Forum on Implementation of the Sustainable Development Goals. 5 - 7 October 2021. Available at: https://www.unescap.org/events/2021/fifth-north-and-central-asian-multi-stakeholder-forum-implementation-sustainable.

cooperation mechanism to reduce and mitigate disaster risks in endorheic (inland) water basins related to the Aral Sea (Figure 3-6). The study served as the basis for expert consultation with experts and key stakeholders of the Aral Sea basin during the regional meeting that ESCAP organized on 14 March 2022. Considering ESCAP's mandate and comparative advantage, two specific recommendations were made:

1. To develop a subregional cooperation framework and suggest an action plan well aligned with the national climate adaptation plan and disaster risk reduction strategies including the SDGs and the Sendai Framework of Disaster Risk Reduction (Figure 3-7); and
2. To organize a policy dialogue on managing the risk of in-land water disasters in the Aral Sea at the side-lines of upcoming sixth North and Central Asian Multi-Stakeholder Forum on Implementation of Sustainable Development Goals to shape a subregional cooperation framework with suggested action plan.

Although the water levels of the Aral Sea may never return to pre-1960s levels, sub-regional cooperation mechanisms on climate change adaptation and disaster risk reduction perspectives provides some hope for the survival of the Aral Sea; helping secure livelihoods of those within its reaches. More than 50 years back, ESCAP/WMO Typhoon Committee and WMO/ESCAP Panel on Tropical Cyclone started modality of sub-regional cooperation across the common ocean basins which substantially reduced the risk of tropical cyclones; Mekong River Commission was a similar effort on transboundary river basin. **Over time, these mechanisms have proved that sub-regional cooperation on disaster risk reduction yields positive results for all.**

Figure 3-7 – Outlining a subregional cooperation mechanism



Methodology Annex

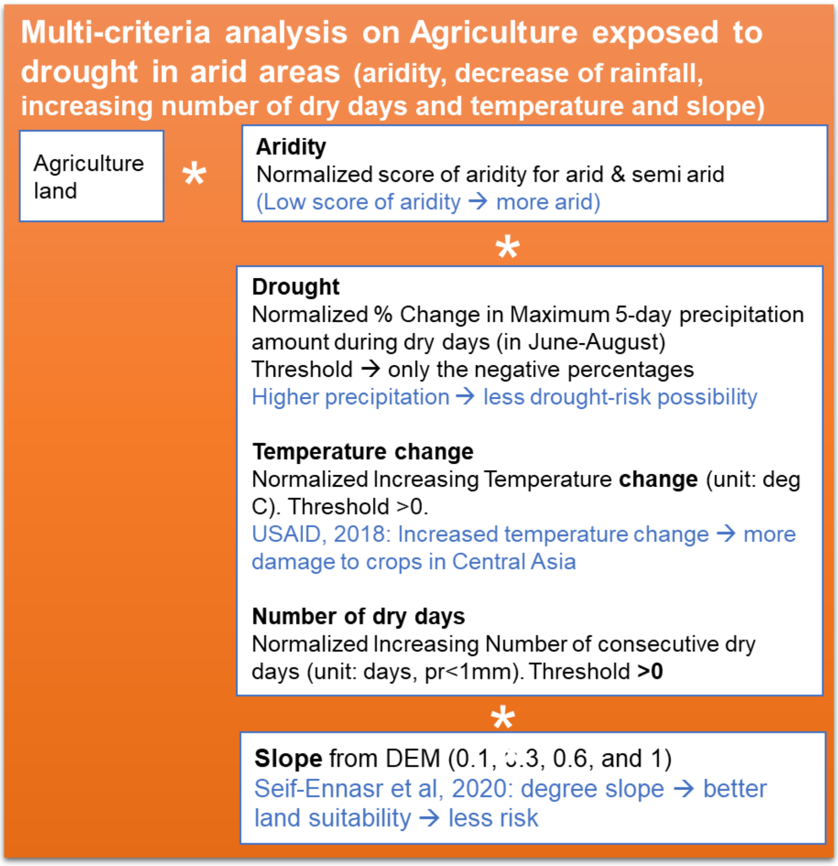
A. Methodology for Agriculture land exposure to multi-criteria indicators for drought and flood

Aridity and drought are the key contributing factors to land degradation and desertification, and will continue to intensify with climate change, increasing their contribution. ESCAP developed a methodology to assess the agriculture land exposure to drought-related climate risk using aridity and projections for environmental risk. Drought is a major environmental hazard that affects large parts of Central Asia. However, this region is also affected by floods, especially flash floods which usually occur on the mountainous areas. To assess the risk of floods, ESCAP has also methodologically quantified the agriculture exposure to precipitation projection, elevation, slope, flow accumulation and soil types.

Agriculture exposure to multi-criteria indicators for drought

The agriculture exposure to multi-criteria indicators for drought was modified based on the *Land suitability assessment method for agriculture in arid land* developed by Marieme Seif-Ennasr and others.[47] There are 3 main variables used in this analysis, namely 1) Aridity, 2) Climate-related data, 3) Slope, and 4) Agriculture data as exposure (Figure 4-1).

Figure 4-1 – Methodology for Multi-criteria analysis on Agriculture exposed to drought in arid areas



[47] Seifennasr, M. and others, (2020). GIS-Based Land Suitability and Crop Vulnerability Assessment under Climate Change in Chtouka Ait Baha, Morocco. Atmosphere 11(1167):25. DOI: 10.3390/atmos11111167.

The first indicator used in this analysis is aridity. Aridity is positively correlated with the risk of drought. High aridity areas have higher risk of increased drought intensity and occurrence, and vice versa.

The next indicator is climate projection which consists of temperature, precipitation and dry days. For precipitation, the selected index is maximum 5-day precipitation change, particularly those recorded during dry season from June to September. Greater increase in precipitation experienced by an area leads to higher possibilities of increased drought intensity and occurrence. Secondly, the increasing annual mean temperature change was selected as an index for temperature. Increase in temperature results in more crop damage.

[48] Third, for the estimation of dry days, we have used annual mean increase in number of consecutive dry days. This index is also positively correlated to drought. Four scenarios were selected for these climate projection data: SSP2 or moderate scenario for near term (2021-2040) and long term (2081-2100) time-period, and SSP3 or the worst-case scenario, for near term (2021-2040) and long term (2081-2100) time-period.

The third indicator is the slope score which is obtained from the digital elevation model (DEM) data. A higher score of slope contributes to less drought exposure on croplands. The fourth indicator is agriculture. We selected agriculture cropland data at 1 km resolution and differentiated them into rainfed and irrigated cropland.

Once the aridity, climate and slope indicators were spatially analyzed through scoring and normalization; these were then combined. Afterwards, the output was overlaid with agriculture exposure and the exposure of agriculture to certain level of drought risks was quantified.

To process the analysis and develop the models, we used spatial analysis such as 3D modeling ArcGIS Pro and QGIS. In addition, we were also using open-source analytical tools such as Cygwin. This tool enables users to download multiple files efficiently, which we used to access the DEM and water body datasets.

Agriculture exposure to multi-criteria indicators for flood

Our analysis on flood focuses on agriculture exposure to climate-related indicators in arid areas. This method uses the following multi-criteria indicators: 1) rainfall intensity, 2) elevation, 3) slope, 3) flow accumulation, 4) soil type and 5) agriculture land as exposure indicator (Figure 4-2). The selection and method of the first four indicators were modified from a study on flood risk mapping on crops by M. Mohammadi in 2021.[49] The exposure indicator used in this analysis is agriculture land, similar to the one used in drought calculation of the previous section.

The index for rainfall intensity is the climate projection data for monthly and annual near-surface total precipitation. This data was used to calculate the rainfall intensity value. Rainfall intensity is positively correlated with flood risk

To calculate elevation, slope and flow accumulation indicators, DEM data was used.[50] Spatial analysis tools were used to process these DEM data to get elevation, slope and flow accumulation values. These indices are also positively correlated with flood risk.

The index for the fifth indicator – soil type, is the permeability of soil. The data is obtained from soil database and classified into several classes based on its water storage capacity. Sandy soil type has good water storage capacity[51], which has negative correlation with flood. On the contrary, silty clay and clay soil

[48] United States Agency for International Developmen (USAID), (2018). Climate Risk Profile – Central Asia. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/2018-April-30_USAID_CadmusCISF_Climate-Risk-Profile-Central-Asia.pdf.

[49] Mohammadi, M., Darabi, H., Mirchooli, F. and others, (2021). Flood risk mapping and crop-water loss modeling using water footprint analysis in agricultural watershed, northern Iran. Nat Hazards 105, 2007–2025 (2021). https://doi.org/10.1007/s11069-020-04387-w.

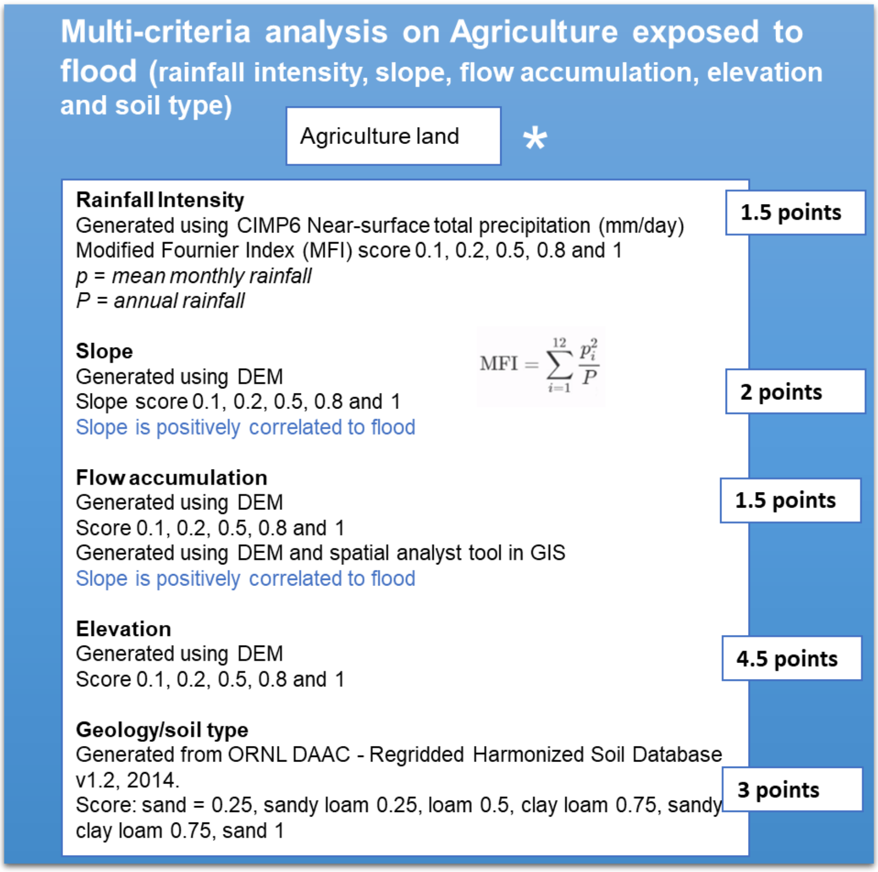
[50] Mohammadi, M and others, (2021).

[51] Huang E. C., Li P. W., Wu S. W., Lin C. W., (2021). Application of Risk Analysis in the Screening of Flood Disaster Hot Spots and Adaptation Strategies. Available at: https://doi.org/10.3390/land11010036.

types has worse water storage capacity, which has positive correlation to flood risk.

After being processed with spatial analysis in GIS, all of these datasets were scored. Based on Mohammadi and others, we weighed rainfall intensity 1.5, elevation 4.5, slope 2, flow accumulation 1.5 and soil types 3. Lastly, these layers were then combined to get the total flood risk hazard. This total flood risk hazard was then overlaid with agriculture land layers to quantify the exposure of agriculture land to flood.

Figure 4-2 – Multi-criteria analysis on Agriculture exposed to flood



Source: ESCAP, modified from "Flood risk mapping and crop-water loss modeling using water footprint analysis in agricultural watershed" by M. Mohammadi and others, 2021.[52]

B. Datasets

This study uses Geographical Information System (GIS) and Multi-criteria Decision Making (MCDM) technique to map the Flood and Drought hazard zones. Different combinations of the data sets depicted in Table 4-1 were used to get the flood and drought risk map for the countries in Central Asia surrounding the Aral Sea basin. The main conditioning factors on flood risk (flow accumulation, slope, projected rainfall intensity, soil type, and elevation) were rated and combined in GIS, and a flood risk map classified into five risk classes (low to very high) was created. Similarly, Conditioning factors (slope, aridity index, projection of decrease in precipitation, projection of increase in Maximum numbers of Consecutive dry days) were combined in GIS to create a drought risk map classified into five risk classes (low to very high).

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[52] Mohammadi, M., Darabi, H., Mirchooli, F. and others, (2021). Flood risk mapping and crop-water loss modeling using water footprint analysis in agricultural watershed, northern Iran. Nat Hazards 105, 2007–2025 (2021). https://doi.org/10.1007/s11069-020-04387-w.

Table 4-1 – List of datasets

No.	Indicators	Sub Indicators	Dataset Name	Data Publication details
1	Projection of Temperature change under SSPs	Mean near-surface air temperature	IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021. Available at: https://interactive-atlas.ipcc.ch/	IPCC, 2021
2	Projection of Number of Maximum numbers of Consecutive dry days change under SSPs	Maximum numbers of Consecutive dry days change	IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021. Available at: https://interactive-atlas.ipcc.ch/	IPCC, 2021
3	Projection of Precipitation under SSPs	Near-surface total precipitation	IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021. Available at: https://interactive-atlas.ipcc.ch/	IPCC, 2021
4	Projection of decrease in percent change in precipitation under SSPs	Maximum 5-day precipitation amount	IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021. Available at: https://interactive-atlas.ipcc.ch/	IPCC, 2021
5	Crop Dominance 2010 Global 1 km V001	Rainfed Croplands Wheat, Rice, Soybeans, Sugarcanes, Corn, Cassava, Barley	Global Food Security Support Analysis Data (GFSAD) Crop Dominance 2010 Global 1 km V001. 2016, distributed by NASA EOSDIS Land Processes DAAC, https://doi.org/10.5067/MEaSUREs/GFSAD/GFSAD1KCD.001.	NASA, 2017
6	Crop Dominance 2010 Global 1 km	Irrigated Croplands Wheat, Rice, Barley, Soybeans, Cotton, Orchards	Global Food Security Support Analysis Data (GFSAD) Crop Dominance 2010 Global 1 km V001. 2016, distributed by NASA EOSDIS Land Processes DAAC, https://doi.org/10.5067/MEaSUREs/GFSAD/GFSAD1KCD.001.	NASA, 2017
7	Global Aridity Index Version 2	a) Arid (AI < 0.2) b) Semi-Arid (0.2 < AI < 0.5) c) Dry sub-humid (0.5 < AI < 0.65) d) Humid (AI > 0.65)	The Global Aridity Index Version 2. Available at: https://cgiarcsi.community/2019/01/24/global-aridity-index-and-potential-evapotranspiration-climate-database-v2/ and https://figshare.com/articles/dataset/Global_Aridity_Index_and_Potential_Evapotranspiration_ET0_Climate_Database_v2/7504448/3.	CGIAR, 2019
8	Digital Elevation Model	N/A	Advanced Spaceborne Thermal Emission and Reflection Radiometer (**ASTER**) Global Digital Elevation Model Version 3 (**GDEM 003**). Distributed by NASA EOSDIS Land Processes DAAC. Available at: https://search.earthdata.nasa.gov/search/ and https://doi.org/ 10.5067/ASTER/ASTGTM	NASA/METI/AIST/Japan Spacesystems and U.S./Japan ASTER Science Team, 2019
9	Global Water Bodies	N/A	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Water Bodies Database (**ASTWBD**) **Version 1**. Available at: https://lpdaac.usgs.gov/products/astwbdv001/.	NASA/METI/AIST/Japan Spacesystems and U.S./Japan ASTER Science Team
10	World Water Bodies	N/A	World Water Bodies. Available at: https://www.arcgis.com/home/item.html?id=e750071279bf450cbd510454a80f2e63. Updated on: 16 October 2021.	ESRI, 2021
11	Soil classification based on soil textures	N/A	ESCAP based on Regridded Harmonized World Soil Database v1.2. Data set. Available on-line [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1247 .	ESCAP, 2022

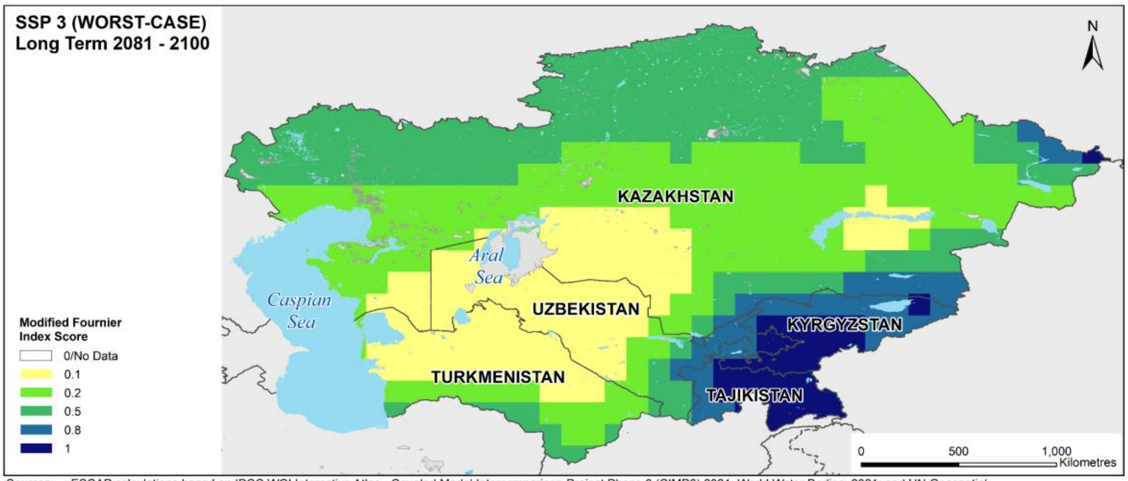
Climate data

The climate data used are explained in Chapter 1.2 of this report. All the layers were processed in ArcGIS Pro. First, the Projection of Number of Maximum numbers of Consecutive dry days change under SSPs was first resampled and clipped for our study area. Further, the negative values in the data were removed and the layers were normalized between 0 and 1. Secondly, the Projection of Temperature change under SSPs was resampled and clipped for our study area. The layers were then normalized between 0 and 1. And third, the Projection of percent change in precipitation under SSPs was resampled and clipped for our study area. The positive values were then removed to get the percent decrease and it was multiplied with -1 to get the degree of percent change without any negative values. It was then normalized between 0 and 1.

Rainfall intensity

In order to calculate rainfall intensity, annual and monthly mean total precipitation under SSP3 2081 - 2100 was used which was then resampled and clipped for our study area.

Figure 4-3 – Rainfall Intesity under SSP3 Long Term



Sources : ESCAP calculations based on IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6) 2021; World Water Bodies, 2021; and UN Geospatial.
Note : 1. MFI scoring is based on Mohammadi Et al. 2021.
2. MFI is calculated from projected Total Precipitation under SSP3 2081 - 2100.
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

The rainfall intensity map shown in Figure 4-3 was created by using the Modified Fournier Index (MFI) methodology[53] as follows

$$MFI = \sum_{p=1}^{12} \frac{p^2}{P}$$

where MFI is the Modified Fournier Index, the 12-month summation, p is the average monthly rainfall, and P is the average annual rainfall. The MFI expresses the sum of average monthly rainfall intensity at a particular area.[54] The MFI was then reclassified into 5 different categories using Jenk's natural break method and then scored for flood analysis.

Aridity

Drought is a recurring event in Central Asia's dry and arid regions, with severe droughts generally occurring once or twice per decade.[55] Drought can occur in any climate region of the world when a period of abnormally dry weather persists for long time and causes a serious hydrological imbalance, however drylands (arid, semi-arid and dry sub-humid areas) are

[53] Morgan, R. P. C., (2005). Soil Erosion and Conservation, Oxford: Blackwell Publishing Ltd. Available at: https://books.google.co.in/books/about/Soil_Erosion_and_Conservation.html?id=j8C8fFiPNOkC&redir_esc=y.

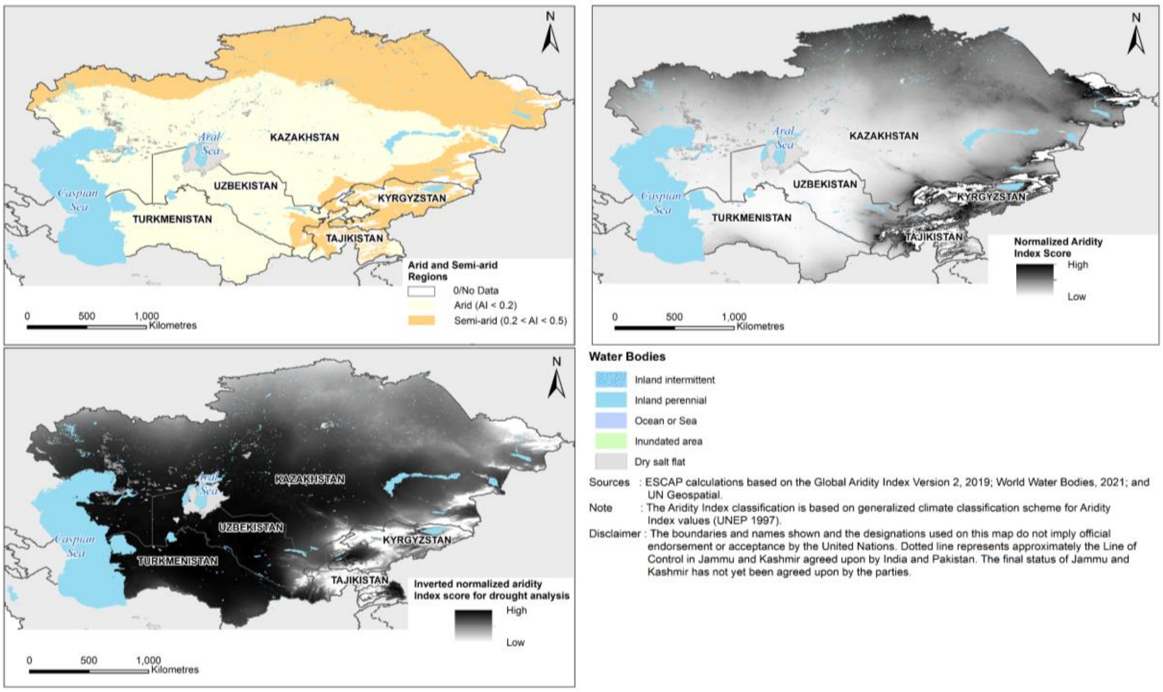
[54] Kourgialas N. N., Karatzas G. P., (2011). Flood management and a GIS modelling method to assess flood-hazard areas—a case study, Hydrological Sciences Journal. Available at: https://www.tandfonline.com/doi/full/10.1080/02626667.2011.555836.

[55] Food and Agriculture Organization of the United Nations (FAO), (2017). Drought characteristics and management in Central Asia and Turkey. Rome: Rome, Italy. Available at: http://www.fao.org/3/a-i6738e.pdf.

more susceptible to drought and its impacts.[56]

Aridity Index (AI) map in figure 4-4 shows normalized Aridity Index score for Central Asia's arid and semi-arid regions. This map was created by clipping spatial data for the Global Aridity Index to the study area. It was then classified using a generalized classification scheme for Aridity Index values into arid and semi-arid regions (AI < 0.5) in central Asia.[57] It was then normalized from 0 to 1 and inverted using geographic information system (GIS) tools to identify areas at increasing risk of land degradation and desertification.

Figure 4-4 – Aridity Index data processing



Land use

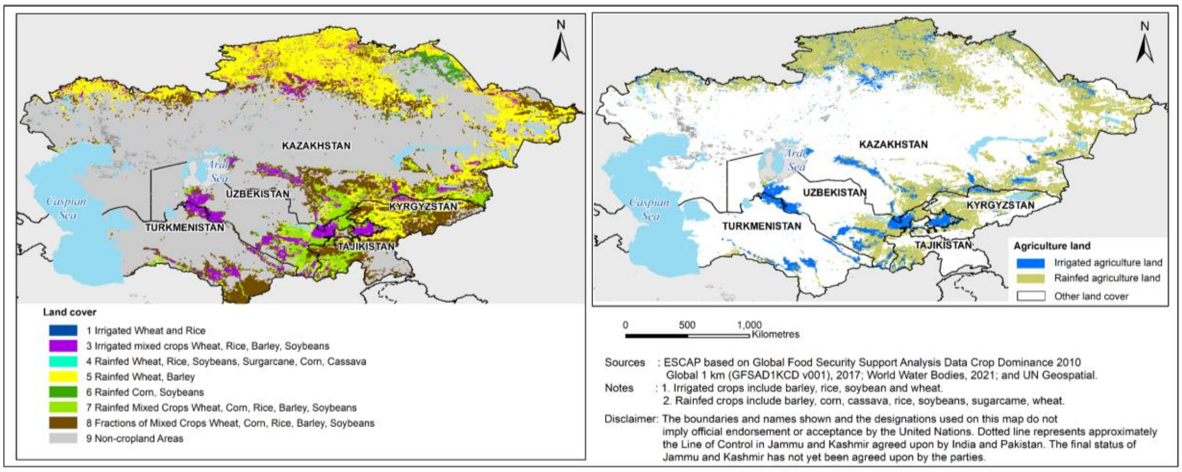
The exposure data consists of rainfed cropland and irrigated cropland. By using the most recent data of NASA's Earth Observation – Global Food Security Support Analysis Data (GFSAD) Crop Dominance (2017) at 1 km, rainfed and irrigated agriculture land including the crop types can be identified (Figure 4-5 a). One layer of rainfed agriculture is obtained from reclassifying the following cropland classes: 1) Rainfed – wheat, rice, soybeans, sugarcane, corn, cassava, 2) Rainfed – wheat, barley, 3) Rainfed – corn, soybeans and 4) Rainfed mixed crops – wheat, corn, rice, barley, soybeans. Then, the irrigated land layer is acquired from reclassifying the cropland classes 1) Irrigated - wheat and rice and 2) Irrigated mixed crops – wheat, rice, barley, soybeans.

These two layers are then normalized to 1, as shown in Figure 4-5 b, they are then overlaid with other raster calculated datasets of aridity, climate and slope.

[56] Intergovernmental Panel on Climate Change (IPCC), (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Available at: https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/.

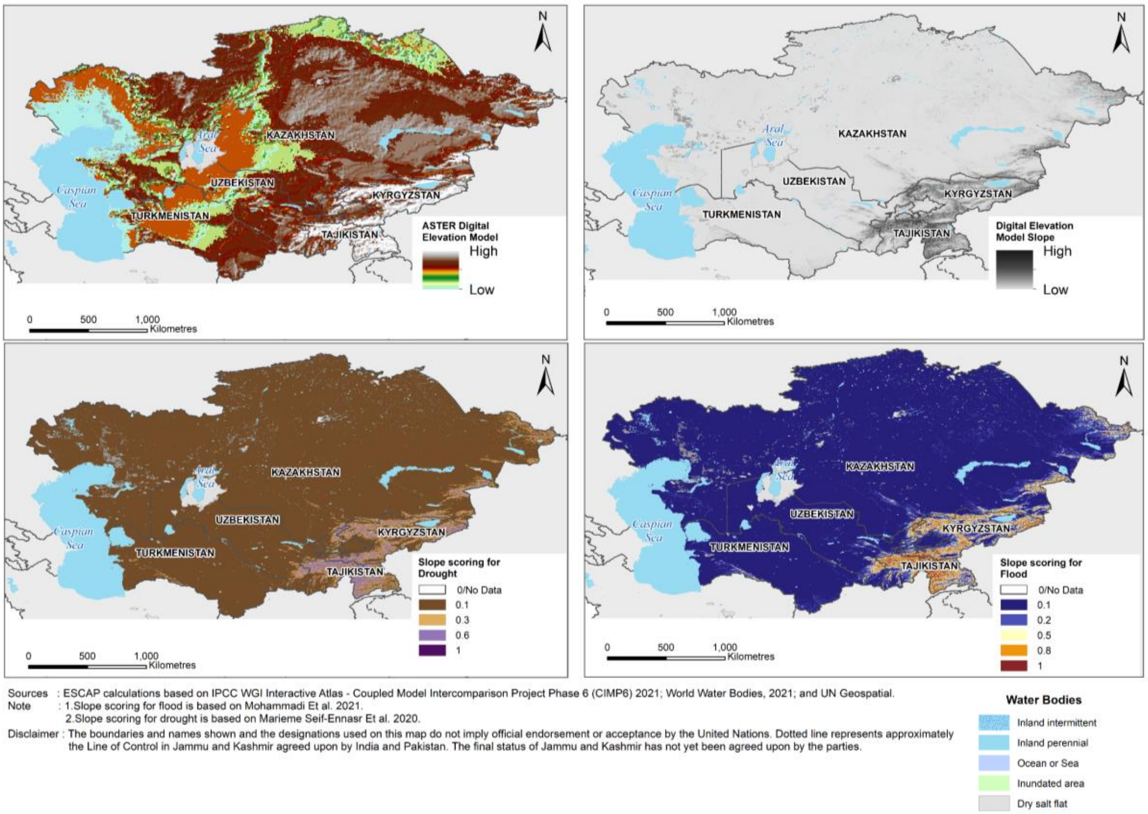
[57] UNEP, (1997).

Figure 4-5 – Dryland agriculture in Central Asian countries, a) Original data, b) Processed data



Digital Elevation Model and Slope

Figure 4-6 – Digital Elevation Model and Slope Map



The Slope shown in Figure 4-6 was calculated as percent rise from Digital Elevation Model layer (DEM) by using the three-dimensional (3-D) Analysis tool after reprojecting the DEM to the appropriate coordinate system and clipping it for our study area. This Slope was then reclassified using the Jenk's natural break method into different classes and scored for drought and flood analysis.

For Drought, the effects of Slope have a greater impact on soil loss. The steeper the Slope, the greater the erosion.[58] Changes in soil texture

[58] Ganasri B. P., Ramesh H., (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin, Geoscience Frontiers, Volume 7, Issue 6, 2016 Available at: https://www.sciencedirect.com/science/article/pii/S1674987115001255.

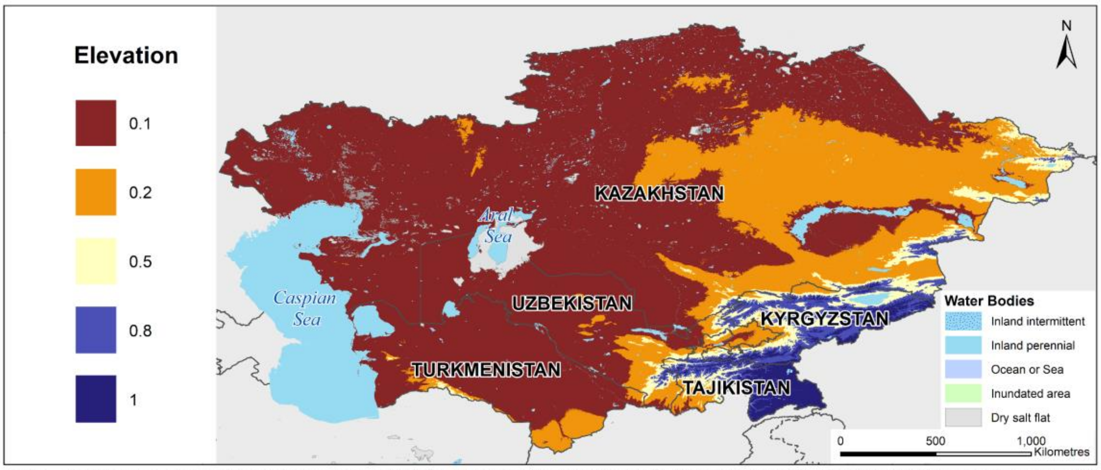
effect the water holding capacity of the soil and make it vulnerable to drought.[59]

For floods, slope is an important determinant in the speed at which drainage channel will convey water, and therefore, influences the sensitivity of a watershed to precipitation events of various time durations. Watersheds with steep slopes will rapidly convey incoming rainfall, and if the rainfall is convective (characterized by high intensity and relatively short duration), the watershed will respond very quickly, with the peak flow occurring shortly after the onset of precipitation. Steep slopes tend to result in rapid runoff responses to local rainfall excess and consequently higher peak discharges.[60]

Elevation

The elevation or the DEM layer shown in Figure 4-6 was first resampled and clipped for our study area. The layer was then reclassified into 5 categories using *the Jenk's natural break method* and scored for the flood analysis. Elevation plays a vital role in controlling surface flow movement and flood depth.[61] In our study area, the highest slopes appear in the south eastern region while the lowest in the north western.

Figure 4-7 – Elevation Scoring for Flood Analysis



Sources : ESCAP calculations based on Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003), 2018; World Water Bodies, 2021; and UN Geospatial.
Note : Elevation scoring is based on Mohammadi Et al. 2021.
Disclaimer : The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Flow accumulation

Flow direction determines the direction in which water will flow based on the Slope of adjacent cells. We first calculated the flow direction using the D8 flow algorithm within an ArcGIS environment's spatial analyst tools to obtain the flow accumulation. The D8 method associates a raster cell's flow direction with its eight surrounding cells. This algorithm determines the direction and allows for a single flow direction toward the cell with the steepest slope gradient.

Flow accumulation raster was generated using the spatial analyst tool in the GIS environment, and the input flow direction was calculated from the DEM. The Flow Accumulation tool calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. Flow accumulation is a key factor in flood risk, as the high value of this layer represents concentrated flow and consequently higher flood risk.[62]

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[59] Masroor M., Haroon S., Sufia R., Roshani S., Rahaman M. H., Mehebub S., Raihan A., Ram A., (2022). Analysing the relationship between drought and soil erosion using vegetation health index and RUSLE models in Godavari middle sub-basin, India, Geoscience Frontiers, Volume 13, Issue 2. Available at: https://www.sciencedirect.com/science/article/pii/S1674987121001766.

[60] Elmoustafa A. M., (2012). Weighted normalized risk factor for floods risk assessment, Ain Shams Engineering Journal, Volume 3, Issue 4. Available at: https://www.sciencedirect.com/science/article/pii/S2090447912000251.

[61] Rahmati O., Darabi H., Haghighi A. T., Stefanidis S., Kornejady A., Nalivan O. A., Bui D. T., (2019). Urban Flood Hazard Modeling Using Self-Organizing Map Neural Network, *Water* 2019, *11*, 2370. Available at: https://www.mdpi.com/2073-4441/11/11/2370.

[62] Mohammadi M., Darabi M., Mirchooli H., Bakhshaee A., Haghighi A. T., (2021). Flood risk mapping and crop-water loss modeling using water footprint analysis in agricultural watershed, northern Iran. Available at: https://doi.org/10.1007/s11069-020-04387-w.

Geology/Soil type

Land use affects the degree of flood disasters, through its impact on the runoff coefficient, volume and flood risk. The soil texture class corresponds to a particular range of separate fraction of soil separates (clay, silt and sand), represented by soil texture triangle in Figure 4-9.[63]

As illustrated in Figure 4-8, this study classified topsoil of the Central Asia in 4 classes based on USDA Textural soil classifications. There are four types of soil textures in the region, namely sandy soils, medium textured loamy soils, moderately fine textured loamy soils, and clayey soils. These were then scored based on their ability to increase or decrease flood risk. Sandy soils have high water permeability and do not easily produce runoff therefore, this class received a low flood risk rating.

Clayey soils received the highest score because they have the lowest water permeability and are predominantly composed of clay, which facilitates runoff.[64]

Figure 4-8 – Soil Texture Map

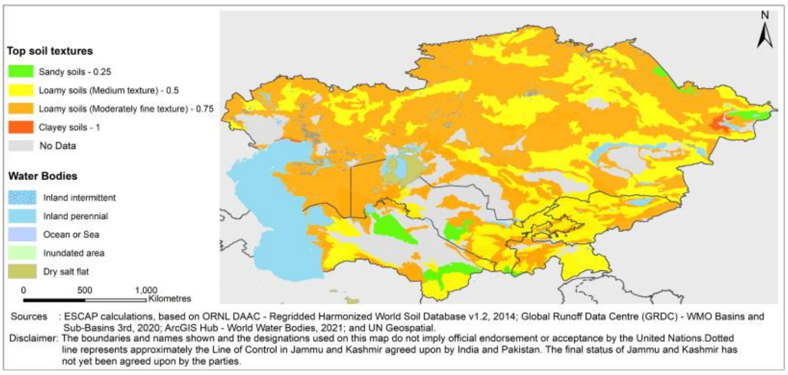
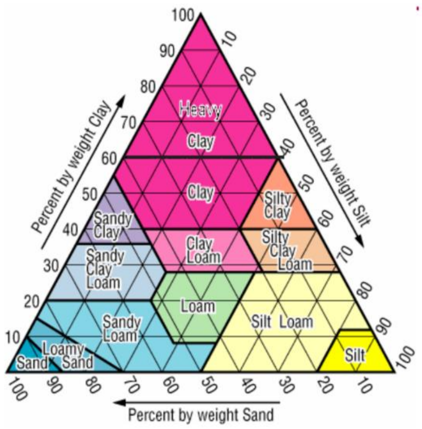


Figure 4-9 – Soil Texture Triangle in FAO, 2009



63 Food and Agriculture Organization of the United Nations (FAO), (2009). International Institute for Applied Systems Analysis (IIASA), ISRIC-World Soil Information, Institute of Soil Science – Chinese Academy of Sciences (ISSCAS), Joint Research Centre of the European Commission (JRC), (2009). Harmonized World Soil Database (version 1.1). Available at: https://www.fao.org/publications/card/en/c/2fa14e5e-ae97-516e-9dd2-24bc7abbc823/.

64 Huang E. C., Li P. W., Wu S. W., Lin C. W., (2021). Application of Risk Analysis in the Screening of Flood Disaster Hot Spots and Adaptation Strategies. Available at: https://doi.org/10.3390/land11010036.